Drone Identication and Tracking in Denmark

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Abstract

New advances in drone technology have sparked an enormous interest in commercial, public and private use of drones. This may become very beneficial to society in many aspects, however at the same time the drones are aircrafts operating in a complex airspace, and the large number of new drones and pilots are expected to become an increasing challenge to the authorities. The Danish Transport and Construction Agency has initiated a series of activities to address these challenges. The aim is to find a balance between supporting the potential industrial growth and business development as well as the recreational users while at the same time maintain a sufficient level of regulation with regards to the identified challenges within safety, security and privacy.

This work deals with the ability to identify and track drones in Denmark to support the authorities in enforcing drone regulation and to be implemented into a UAS Traffic Management (UTM) system. The focus has been on establishing a proof of concept in a short period of time rather than seeking optimal solutions to all technical parts of the project. The work has included interaction with drone pilots, technical and non-technical domain experts, decision makers, authorities, governmental agencies, the industry and politicians via workshops, formal and informal meetings, knowledge sharing etc. This heterogeneous group of stakeholders also represent the target audience for the reporting of this work, therefore a technical report was chosen rather than a scientific paper. Focus has been on conveying results and findings at a generic level while at the same time providing the details necessary for experts to build upon this work.

Based on input from the stakeholders a system design for drone identification and tracking has been proposed. The system design supports communication between the drone and the UTM via either a local beacon signal or a radio network infrastructure. The required drone functionality may be implemented by the manufacturer or the drone may be retrofitted with an external DroneID device.

Parts of the system design including a prototype of the external DroneID device were implemented and tested in an experiment. A group of 10 professional drone pilots were issued each an external DroneID device. During a 30 day period they then carried out their usual drone operations with the DroneID device installed and thereby actively transmitting information about the drone flight to an experimental UTM server. Weather conditions prevented drone flights on many days during the experiment. 19 pilot flight days were recorded, each with 2-4 takeoffs. The recorded flights did provide valuable knowledge concerning the pilot interaction with the DroneID device and helped testing the hardware and software. Data received by the UTM has been analysed and compared with detailed logs provided by the pilots. Some issues concerning technical design and usability were discovered, and the proposed system design has been updated accordingly.

It is concluded that to the extent tested in this work it is feasible to efficiently identify and track drones fitted with the external DroneID device by a UTM service. The project partners have agreed to continue this work: A new version of the external DroneID device is currently being developed and a larger scale integration experiment will be conducted in 2017. Software and hardware developed within this work has been released as permissive free open source for others to build upon.

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Reading guide

Section 1 describes the domain and problem leading to the DroneID project. The scope and delimitation of the work is discussed in 1.1 and reference information and known related work is presented in 1.2.

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Section 3 describes the DroneID system design based on requirements and design goals from the authorities, agencies, operators and pilots as well as the experience obtained throughout the project.

Section 4 describes the DroneID device developed in the fall 2015 for the field experiment described in section 5.

Section 5 describes a 30 day field experiment conducted during November and December 2015. A group of 10 profesional drone operators were issued each a DroneID beacon prototype and used it while flying for one month.

Section 6 describes the outcome of two workshops for public authorities and agencies held during the 30 day field experiment.

Section 7 discusses the project results in relation to future work.

Section 8 contains the report conclusion.

Several names and abbreviations have been used to describe unmanned aircrafts such as Unmanned Aerial Vehicle (UAV), Unmanned Aerial System (UAS), Unmanned Aerial Device (UAD), Remotely Piloted Aircraft (RPA), Remotely Piloted Aircraft System (RPAS) etc. Throughout this report the term *drone* will be used.

Drones weighing from 250g to 25 kg are named *small drones* or just *drones*. Drones with a weight below 250g are named *microdrones* and drones with a weight above 25kg are named *large drones*. The reasoning behind these weight thresholds is elaborated in section 1.1.1.

A *drone operator* is the legal entity (e.g. a company or a private drone owner) having the overall responsible for drone activities. The *drone pilot* is the person conducting the actual drone flight.

The external DroneID device described in section 4 was developed in the fall 2015. This version is referred to as the *DroneID* or *DroneID v1*. The version being developed at the time of publication of this report is referred to as *DroneID v2*. Other names have been used in relation to this and similar projects. Examples are *Electronic ID*, *Electronic Numberplate*, *IDrone* etc. These names will not be used.

This work concerns a system for drone identification and tracking in Denmark. Such a system is considered to be a component of the Unmanned Aerial Systems (UAS) Traffic Management (UTM) system presented in section 1. In this report the term *UTM* is used to describe the central part of the drone identification and tracking system formed by database(s), server(s) etc. even though more functionality will expectedly be added to this system in the future.

Abbreviations

ADS-B	Automatic Dependent Surveillance – Broadcast
A-NPA	Advance Notice of Proposed Amendment
ADC	Analog to Digital Converter
AGT	APR Global Tracking
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
BVLOS	Beyond Visual Line Of Sight
C2	Command and Control
CAA	Civil Aviation Authority
CRC	Cyclic Redundancy Check
DAE	Drone Alliance Europe
DEA	Danish Energy Agency
DECT	Digital Enhanced Cordless Telecommunications
DEMA	Danish Emergency Management Agency
DTCA	Danish Transport and Construction Agency (Trafik og Byggestyrelsen)
EASA	European Aviation Safety Agency
EMI	Electromagnetic Interference
FIU	Flight Integrity Unit
GBSAA	Ground Based Sense And Avoid
GCS	Ground Control Station
GHz	Giga Hertz
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
IMU	Inertial Measurement Unit
ISM	Industrial, Scientific and Medical
IoT	Internet of Things
KSDK	Kinetis Software Development Kit
LED	Light Emitting Diode
LHCP	Left Hand Circular Polarization
Li-ion	Lithium Ion
LOS	Line Of Sight
LP	Linear Polarization
LoRaWAN	Long Range Wide Area Network
LPWAN	Low Power Wide Area Network
LTE	Long Term Evolution
M2M	Machine to Machine
mA	milli Ampere
MHz	Mega Hertz
mAh	milli Ampere hours
NAA	National Aviation Authority
NASA	National Aeronautics and Space Administration
NMEA	National Marine Electronics Association
NOTAM	NOte To AirMen
OEM	Original Equipment Manufacturer
PA	Polyamide (nylon)

PCB	Printed Circuit Board
PLF	Polarization Loss Factor
PE	Processor Expert
ReWiLink	Resilient Wireless Link
RF	Radio Frequency
RFID	Radio-Frequency Identification
RHCP	Right Hand Circular Polarization
RPA	Remotely Piloted Aircraft
RSSI	Radio Signal Strength Indicator
RTOS	Real Time Operating System
SAA	Sense And Avoid
SDU	University of Southern Denmark (Syddansk Universitet)
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaking
SLS	Selective Laser Sintering
SMD	Surface Mounted Device
SNR	Signal Noise Ratio
SOC	State Of Charge
sUTM	UTM system for small UASs
SWaP	Size, Weight and Power
TCL	Technology Capability Levels
UA	Unmanned Aircraft
UAD	Unmanned Aerial Device
UART	Universal Asynchronous Receiver/Transmitter
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UDP	User Datagram Protocol
UHF	Ultra High Frequency
UTM	UAS Traffic Management
VDL	VHF Data Link
VHF	Very High Frequency

Intellectual property rights

It has been agreed between DTCA and SDU that in order to facilitate the future development and deployment of DroneID, the work undertaken in this project will be made available for others to build upon.

Electronic and mechanical design and development of the DroneID device by SDU not building upon prior copyrigted work will be released under the Attribution 4.0 International (CC BY 4.0) license. Software written for the DroneID device by SDU not building upon prior copyrighted work will be released under the BSD 3-Clause license.

All relevant documents concerning the DroneID device mechanical design, schematics, software and documentation released under the above mentioned licences are available at the project repository:

https://github.com/SDU-UAS-Center/DroneID.

1 Introduction

This section describes the domain and problem leading to the DroneID project. The scope and delimitation of the work is discussed and known related work is presented.

Only few years ago drones were used almost exclusively for military purposes and by dedicated hobbyists flying from registered model airplane airfields. New advances in drone technology however have resulted in new functionality, enhanced usability and lower cost which have made made the drones accessible to everyone. This has sparked an enormous interest in using drones for commercial applications such as farming, inspection, security, payload delivery, surveying etc., public applications such as state and municipal applications, environmental monitoring, law enforcement, emergency management and research, as well as for recreational use such as aerial photography, filming or just flying for fun [1, 2]. Today thousands of drones for both commercial and recreational use are sold from more than 300 websites, electronics stores and supermarkets in Denmark alone[1] and sales are increasing rapidly: One of the biggest Danish retailer of consumer electronics reportedly had a 50% increase of turnover on drone products during the Christmas sale in 2015 compared to 2014[2].

The new possibilities provided by the advances in drone technology may become very beneficial to society in many aspects as exemplified in [3]. At the same time the drones are also aircrafts operating in a complex airspace, and the large number of new drones and pilots is expected to become an increasing challenge to the authorities. To mitigate this the aviation authorities in many countries are currently working on updating the regulatory framework to include drone flights. The aim is to find a balance between supporting the potential industrial growth and business development as well as the recreational users while at the same time maintain a sufficient level of regulation with regards to the identified challenges within safety, security and privacy [4].

One of the central topics discussed is Unmanned Aerial Systems (UAS) Traffic Management (UTM) which is a concept to enable safe low-altitude civilian operation of drones. The overall functionality includes providing the authorities information about planned and ongoing drone flights as well as provide drones and drone pilots information needed to maintain separation from permanent or temporary no-fly zones and other aircrafts etc. UTM is still in early development, section 1.2 describes some of the current activities.

The Danish Civil Aviation Authority (CAA) is currently focusing their activities concerning UTM on the ability to identify drones and monitor drone flights online and historically. The incentive is that drone identification and tracking may improve the police and other authorities ability to enforce drone regulation and serve as a warning system if a drone gets too close to no-fly zones. Developing the technology to support this is not trivial, the Danish Transport and Construction Agency (DTCA) and the UAS Center at the University of Southern Denmark (SDU) therefore launched a fast track project with the aim to build knowledge and experience in drone identification and tracking.

[1] Danish Droneforum meeting 2016-01-06

[2] http://www.dr.dk/nyheder/indland/droner-er-aarets-helt-store-julegavehit

1.1 Scope and delimitation of the work

The scope of this work is to propose a system design for a drone identification and tracking system, to develop a first prototype of the system and to conduct a field experiment to validate the feasibility of the system. In terms of technology the main focus is on the device being implemented or retrofitted on the drones to enable tracking.

This technical report documents the knowledge and experience obtained during this project named *DroneID*. The aim is to disseminate at an early stage to support current development and decision making processes in Denmark and abroad even though parts of the project need to be explored in more details.

The project description is detailed in section 2. Section 1.1.1 and 1.1.2 describe project delimitations.

1.1.1 Drone types

The Danish report on future regulation of drones [4] and the Danish proposal for new legislation concerning drones describe that drones with a weight higher than 25 kg are subject to the general aviation law. A triviality threshold of 250 g was initially part of a proposed new Danish aviation law and was thus expected to be approved during the timeframe of this project. The triviality threshold was, however, removed from the new aviation law before approval by the Danish parliament in May 2016, instead the Minister of Transportation was appointed the ability to regulate this at a later stage. Based on this the project focus on drones within the weight range 250 g to 25 kg.

1.1.2 Privacy

DroneID will inherently support monitoring current and historical activities carried out by drone pilots and operators. This includes their geographical location with respect to time, their flight activities etc. which may be information that the pilot and/or operator may desire to keep private for commercial or private reasons. The implementation of DroneID will thus expectedly lead to a debate about privacy. The authors finds that this debate is important, but it is beyond the scope of this project and is thus only discussed with respect to technology supporting and ensuring any decided level of privacy.

1.2 Related work

Below is a listing of related prior and current work that are known to the authors. The related work includes political and administrative discussions and proposals that are considered relevant to the system functionality and design. Many new initiatives are being initiated in these months, and the list should not be considered exhaustive. We first describe international and national initiatives, then research and commercial initiatives.

1.2.1 International initiatives

European Commission
The European Commission states in the Riga Declaration [5] that "it will be necessary for drones to have at all times an identifiable owner or operator. The regulator should seek the least bureaucratic way to achieve this. For instance, the mandating of electronic identity chips on drones *IDrones* as is today envisaged in some states, could be formalised through a safety rule which would contribute to the effective implementation of privacy and security requirements. Standardised web portals in the Member States for the registration of operators and their operations could be another solution."

European Aviation Safety Agency
The European Aviation Safety Agency (EASA) published in 2015 a Technical Opinion [6] to the Advance Notice of Proposed Amendment (A-NPA) 2015-10 *"Introduction of a regulatory framework for the operation of unmanned aircraft"* [7]. Both documents deal with some of the functionality that defines UTM. The Technical Opinion states that registration and the possibility of identification of operators is a very effective instrument to improve compliance with regulations and to enable enforcement. It further advocates that a functionality that automatically identifies and generates geographical limitations of the unmanned aircraft for certain unmanned aircraft and operation areas should be mandated.

For the identification system it is suggested that the technologies like cell-phone networks or Radio-Frequency Identification (RFID) may be used. A portable chip providing that function independently could be attached to the unmanned aircraft in operation.

The Technical Opinion proposes that National Aviation Authority (NAA)s may define no-fly zones where no operation is allowed without authority approval to be published by service providers, smartphone apps or directly uploaded to the unmanned aircraft. It is further suggested that no-fly zones are applicable in a dynamic way to support operators and pilots in complying with temporary limitations or even local needs, e.g. to create a safe bubble around a rescue helicopter when landing at the accident site.

In August 2016 EASA published a *Prototype Commission Regulation on Unmanned Aircraft Operations* [8]. In Appendix I.6 *Product requirements for UAS components* it is stated that *"Electronic identification shal mean a function to identify a Unmanned Aircraft (UA) in flight without direct physical access to that aircraft. The system shall transmit the following data as applicable according to standards acceptable to EASA: The registration of the operator; the class of the UAS; the type of UA operation; the status of its geofencing; its position and height. Where required for the airspace of the operation, a management function according to standards acceptable to EASA should, in addition to the function required above, provide functions to: Transmit information on the intended flight plan and changes to it during operation; receive information on the acceptance of flight plans and related authorizations; receive infromation on other manned aircraft or UA operations; receive information on temporary restricted and prohibited airspace areas or volumes."*

In September 2016 EASA published a report: *Study and Recommendations regarding Unmanned Aircraft System Geo-Limitations* [9]. The report presents in Appendix I *evolving technology solutions* and presents some work within air traffic situational awareness, unmanned aircraft in-flight identification and UTM.

Single European Sky ATM Research
Single European Sky ATM Research (SESAR) Joint Undertaking (SJU) was created under European Union law on 27 February 2007, with Eurocontrol and the European Union as founding members, in order to ensure the modernisation of the European air traffic management system by coordinating and concentrating all relevant research and development efforts in the Union[3]. SESAR has in June 2016 established a number of 2020 RPAS exploratory research calls, of which some are directy related to UTM and drone identification and tracking. Examples are "SESAR UTM Concept Definition" and "Drone information management".

Drone Alliance Europe
The Drone Alliance Europe (DAE) is a coalition of technology and drone companies from across Europe working *"to build the safest and most dynamic European market possible: a single home market for autonomous operations, savvy political support, and a public that champions drone technology"*[4]. DAE has published a white paper on Drone Traffic Management in Europe[10] which advocates that the success of the European drone industry requires a network of low-cost, interoperable UTM system providers working on common standards, to ensure that all drone operations are safely integrated into the airspace efficiently. According to DAE the UTM system must: Be an integrated single system made up of multiple subsystems operating on common standards; Be based on open source standards; Facilitate competitive service offerings from all parts of the industry; Work from reliable, dynamic, data sources; Facilitate, without overburdening, recreational users; Allow for appropriate geofencing; Be accompanied by a reliable registration and identification service; Be available at a transparent and reasonable cost.

Global UTM Standardization Group
In June 2016 the Global UTM Standardization Group[5] was established bringing together drone manufacturers, operators, regulators, air navigation service providers, infrastructure suppliers and academic experts. The goal is to coordinate existing efforts to create global standards and interoperable systems for the rapidly expanding civilian drone industry. Due to the short time, the group has existed, no recommendations or statement of policy etc. has been published yet, but this is expected in the near future[6].

1.2.2 National initiatives

Denmark
In Denmark an inter-ministerial working group published a report named *Future regulation of civil drones* in 2015. The working group recommended that "A requirement should be introduced concerning electronic identification ("number plates") for drones for professional use, starting with drones in a congested area. The requirement will apply both above and below the triviality threshold, in cases where drones are equipped with a camera or similar device. Given that this constitutes primarily

[3] http://www.sesarju.eu
[4] http://dronealliance.eu
[5] http://utm.aero
[6] Christian Struwe, Vice Precident, Global UTM Standardization Group.

an operational regulation, it does not accordingly involve a technical trade barrier under EU law. On policing grounds, consideration should also be given to bringing in this requirement for drones for professional use outside of a congested area, and, at a later date, for recreational drones. The ID requirement is supplemented with a requirement for drones to carry lights so that their presence can be clearly identified. The purpose of drone “recognition” is to safeguard citizens against invasion of privacy and to allow the police greater scope in enforcing “traffic regulations” and other requirements. The specific technical solution will be developed in coordination with the industry and research institutions in 2015. It is recommended that the solution eventually be map-based, allowing identification of drones within a given area." [4]

Another recommendation by the working group was that "Drone operators must be able to readily gain access to information about closed airspace and other restrictions, so as to prevent inadvertent drone use where it is not permitted. The most appropriate approach would be to link the design of this airspace information to the existing NOte To AirMen (NOTAM) system for general aviation, where a lot of data can be reused. It is proposed that in 2015 Naviair[7] (the Danish ANSP) draft a proposal for traffic information specifically designed for flying drones in a separate airspace. The proposal should include some indication of financing requirements and options. The long-term aim is that private app developers should have easy access to high-quality airspace data from Naviair, so that the market can develop user-friendly applications on its own."

A working group under the organization UAS Denmark[8] was in 2014 tasked by TBST to identify possible technologies for a drone electronic identification solution. In november 2014 interim results by the working group were presented at a national drone forum meeting. A solution was proposed based partly on manual registration of planned flights using an app or a web interface prior to flying, and partly on radio technologies for drone identification and possible tracking. The applicability of some radio standards and spectrum was assessed in the resulting report [11]. The working group continued its work during the spring 2015 where field range experiments were performed using early prototypes of Digital Enhanced Cordless Telecommunications (DECT) and Ultra High Frequency (UHF) Industrial, Scientific and Medical (ISM) 433 MHz radio band based beacons. Most impressive was the DECT beacon which installed at a fixed location approx. 8 m above ground was readable at a range of 2 km with no obstacles in between.

USA

In USA the National Aeronautics and Space Administration (NASA) is researching prototype technologies for a UTM system. According to the NASA UTM website[9] the near-term goal is the development and demonstration of a possible future UTM system that could safely enable low-altitude airspace and UAS operations.

The work is structured in deliverables of increasing Technology Capability Levels (TCL). TCL 1 in August 2015 demonstrated flight operations for agriculture, firefighting and infrastructure monitoring focusing on geofencing, altitude "rules of the road" and scheduling of vehicle trajectories. TCL 2 in October 2016 is expected to demonstrate a more mature version and focus on Beyond Visual Line Of Sight (BVLOS) operations in sparsely populated areas. Further TCL’s are planned moving

[7] http://naviair.dk
[8] http://www.uasdenmark.dk
[9] http://utm.arc.nasa.gov

towards collaborative drones, more challenging tasks such as package delivery and more challenging environments such as higher-density urban areas.

The latest published result is from April 2016 where NASA and the Federal Aviation Authority (FAA) completed a 3 hour drone traffic management test involving a total of 24 drones, of which 22 were flying simultaneously at one point. NASA's UTM research platform checked for conflicts during the flight, gave approval or rejections to flight plans and delivered notifications on constraints to the users.

France
In France the General Secretariat for Defence and National Security was tasked to organise an inter-ministerial study on the subject and presenting proposals to enable a more effective fight against the malicious use of drones. The report *The developing use of civil drones in France: Issues and possible State responses* was published by the General Secretariat in 2015. The report suggests that in order to facilitate its tracking, each drone weighing more than 1 kg should be equipped with a radar/beacon for transmitting certain information using Global System for Mobile communications (GSM) or RFID: Identity of the owner, telephone number, drone registration number, three-dimensional geographical coordinates of the position of the drone. This electronic signalling could be supplemented by an obligation for specific lighting by Light Emitting Diode (LED) to allow drones to be distinguished more easily, particularly at night. The technologies proposed are inexpensive to put in place and would not harm the performance of the drones [12, p.33].

Great Britain
In 2015 the House of Lords published a report on civil drones[1, 248]. The report states that the authors "forsee the need for a system which can track and trace all drones, especially those flying below 500ft, irrespective of whether they are flown by commercial or leisure pilots. This will be essential not only to manage the increased traffic in the sky, but also to enforce existing and future laws governing drone use". In an official comment to the report it was added that the general public should have access to the tracking database via an app.

Other countries
Based on information communicated at meetings etc. the authors are aware that in addition to the above listed initiatives and activities, other countries are working with drone tracking and UTM as well. However this section lists only initiatives and activities where a public source of information has been identified.

1.2.3 Research

Kim et al. [13] analysed the requirements of a specialized UTM system for small UAS (sUTM), designed a communications architecture and demonstrated a proof of concept prototype using simulated data. The proposed functions of sUTM are *Flight authorization:* The operator can register and get flight authorization along with info about restrictions, weather conditions, nearby manned or unmanned aerial activity etc.; *Airspace seperation:* Through real-time position reporting a Ground Based Sense And Avoid (GBSAA) system can be established; *Recovery and investigation:* Registration and tracking may help an investigation, and a lost UAS can be located through the sUAS system.

Foina et al. [14] presents a UTM system comprising three components: a UAS electronic identification plate with an embedded logger, a ground identification equipment, and a Traffic Routing System (TRS). A LED array that transmits a code by blinking in a unique color is propoed as the identification plate. The LED array is supplemented a UHF radio transponder which broadcast the same code along with the current position to be used for for both identification and collission avoidance. The communication between transponder and a ground receiver is unidirectional. In a subsequent publication Foina et al. [15] reports from esperiments with a Flight Integrity Unit (FIU) which is essentially an Android phone with apps capable of transmitting real time identification and non-real time flight analysis data.

Limbaugh et al.[10] filed in 2007 a patent titled *Unmanned aerial system position reporting system* US 8386175 B2. The patent abstract describes: *An unmanned aerial system (UAS) position reporting system. Implementations may include an air traffic control reporting system (ATC-RS) coupled with a ground control station (GCS) of an unmanned aerial system where the ATC-RS includes an automatic dependent surveillance broadcast (ADS-B) and a traffic information services broadcast (TIS-B) transceiver and one or more telecommunications modems. The ATC-RS may be adapted to receive position data of the UAS in an airspace from the GCS and communicate the position of the UAS in the airspace to a civilian air traffic control center (ATC) or to a military command and control (C2) communication center through an ADS-B signal or through a TIS-B signal through the ADS-B and TIS-B transceiver. The ATC-RS may also be adapted to display the position of the UAS in the airspace on one or more display screens coupled with the ATC-RS*

1.2.4 Commercial initiatives

In addition to the above listed initiatives and activities a number of companies are working on commercial products and services to be offered to NAA's and other relevant stakeholders. In this work SDU has collaborated with three Danish companies who are in the process of developing products within drone tracking systems and hardware. They are described in section 6.2. Examples of other commercial products and services currently available or being developed are listed below:

The company Rienergygroup[11] (Milano, Italy) is working on a drone tracking service named APR Global Tracking (AGT). AGT consists of a cloud based tracking website and embedded air and ground modules for drone tracking via radio beacons on 868 MHz. Presentations of the AGT can be found at the RIENERGYGROUP YouTube channel.

The company UniFly[12] (Antwerp, Belgium) provides a *Small UAS Flight Planning and Management System (UniFlyUMTS)* which supports planning of drone flights and validation against geofenced areas as well as live monitoring of drone flights. UniFlyUMTS supports both mobile and web-based platforms.

The company Nokia[13] (Espoo, Finland) has showcased a UTM concept to manage safe operations of drones equipped vith Long Term Evolution (LTE) dongles, GPS and access modules for telemetry data. The showcase includes components to mon-

[10] https://www.google.com/patents/US8386175
[11] http://www.rienergygroup.it
[12] http://unifly.aero
[13] http://company.nokia.com

itor airspace, view and control drone flight paths, and transfer telemetry data and establish dynamic no-flight zones, and a mobile app.

The company UgCS[14] demonstratedin January 2016 what they believe is a first, integrating a Mode S Automatic Dependent Surveillance – Broadcast (ADS-B) transponder with a small drone (DJI A2), enabling radar visibility throughout the drone's flight. ADS-B is an existing radio transponder system used to transmit manned aircraft position and status to Air Traffic Control (ATC) ground stations and to other aircrafts. The Sagetech XPG-TR used in the experiment is claimed by the company to be the World's smallest. The size of the transponder is 89x46x18 mm and the weight is 100 g excluding battery.

The company Trackimo[15] (New York, USA) provides a GSM/GPS tracking product for various applications including drone tracking. The product consist of a tracking device and accompanying app which contains many of the features relevant for UTM such as geofencing, multiple device tracking etc. The website claims World wide cellular coverage at a cost of $60 annually per unit. The hardware tracker weighing 42g includes quad band GSM and claims an operation time of 48-96 hours. Trackimo has a pending patent on *"System and Methods which Use Low Wireless Data Bandwidth Consumption for Tracking Wandering Devices"* which is described at their website.

LightCense [16] (California, USA) is a low-altitude identification system for UAS that uses visible color blink sequence to create an identification system. The blink sequence can either be remembered or captured and decoded by a smartphone app. The website claims that the LED can be seen more than 100 m from the drone.

1.2.5 Discussion

The listed international and national initiatives clearly state the need for an implementation of UTM in the near future to enable safe, efficient low-altitude operations of small drones. The identification and tracking of small drones is an integral part hereof. Various commercial and public stakeholders are working on the development of UTM systems at different levels of functionality, where tracking is a typical feature. So far only NASA seems to have conducted tests at a larger scale though. Some companies have developed prototypes of identification and tracking devices for small drones. Common to those identified in this work is that due to their chosen means of signalling, size, weight, applicability to lightweight drones and level of testing they are not at the current state of design and development suitable for implementation, at least not in a Danish context.

Based on this, the project scope described in section 1.1 and 2 is expected to provide new knowledge which may prove valuable in future development of UTM. The primary focus should be on the design and field testing of the DroneID device and communication with the UTM service.

[14] http://www.ugcs.com
[15] http://trackimo.com
[16] http://www.lightcense.co

2 Project description

This section presents the project description as agreed between DTCA and SDU in the Summer 2015. The project tasks are outlined at the end.

The purpose of the DroneID project is to analyse the feasibility of deploying a drone identification and tracking system in Denmark as well as internationally by use of electronic identification devices (informally named number plates) attached to the drones. The aim of DroneID is to allow authorities to be able to identify and monitor drones online as well as historically. Due to the rapid development in the use of drones time is a critical factor. It was decided to limit the first phase of the project to a period of 6 months and from the obtained results decide the further process. It was also decided to focus primarily on conducting a field experiment in which a group of professional drone operators in a period would be monitored while they carried out their drone operations.

The project builds upon a tentative analysis including field tests conducted by a working group under UAS Denmark described in section 1.2. Based on this analysis and the current state of knowledge at DTCA at the beginning of the project the following assumptions were made:

- The use of DroneID will be required in only cities and a number of selected areas.
- DroneID will be used by operators operating with authorization from DTCA i.e. not all drone owners will be allowed to fly in cities.

Within the project a number of tasks is to be achieved:

1. Develop an external DroneID device prototype using GSM technology. If possible in collaboration with an external company also develop an external DroneID prototype transmitting a local radio beacon signal.
2. Develop a tentative UTM database for testing purposes with web access which will allow online monitoring of drone flights. The user interface of the web interface is for testing purposes only. If possible in collaboration with an external company also develop a mobile app to demonstrate mobile access.
3. Perform a feasibility test by having 10 active drone operators from the UAS Denmark network use the DroneID during flights and at the same time run an accurate log for reference.
4. Publish the DroneID device development and the test results.

3 System design

This section proposes a system design for drone identification and tracking in Denmark. Design criterias and goals and their origins are presented and discussed.

As stated in section 1.1 the scope of this work includes proposing a system design for a drone identification and tracking system which forms part of the overall UTM system. At the time of project launch the system requirements were defined in very general terms only. As knowledge was gained through the project and a parallel administrative and political process of updating the Danish aviation law concerning drones, the system requirements became more well defined and were also modified in some areas. This section presents a system design described retrospectively. It is based on a combination of background knowledge available at project launch, knowledge of related work and foreground knowledge gained within the project.

3.1 User perspectives

This section deals with the design specifications and goals from a user perspective. The users of the UTM system have been identified as the drone operators and pilots, any public authority and agency with an interest in drone activities, and the public. In section 3.1.1 to 3.1.3 requirements and design goals based on the perspective of these entities are described.

3.1.1 The perspective of public authorities and agencies

The Danish public authorities and agencies with an interest in monitoring drones have been identified to be the national police, the national emergency management agency, the defence, the national Air Navigation Service Provider (ANSP) and the CAA. As detailed in section 6 these stakeholders have contributed to this work through meetings, workshops and written statements. Below the feedback relevant to the system design is listed:

The system must support drone activities within cities which by the current aviation law is only permitted by professional drone pilots. The system may also be extended to support drones outside cities.

The system must support current, historical and if relevant planned drone flights. This information must be accessible anywhere without requiring e.g. police officers or infrastructure near the drone of interest.

The information should be accessible by police officers on foot and may thus not require excessive extra equipment, fixed installations in police vehicles, on nearby buildings etc.

The authorities must be able to retrieve contact information for a drone flight in order to be able to contact the drone pilot etc.

The police expects a significant amount of inquiries from citizens who have observed a nearby drone. To the extent possible this should be mitigated by the system.

The system should support static and dynamic geofencing, and inform the drone pilot about the current state of the flight authorization.

The ANSP has stated that use of ADS-B for small drones is not a viable solution. It may be a solution with regards to larger drones, but for small drones the ANSP expect that the ADS-B system will be overloaded. As described in section 1.2.4 transponders are also not yet available in a size and weight configuration suitable for all small drones.

The CAA expects that the system will be implemented as soon as technologically feasible. The system must be applicable to both new and existing drones.

3.1.2 The operators/pilots perspective

Drone pilots can be divided into professional and recreational pilots. The professional drone pilots are employed by a drone operator which may be a commercial company, governmental or municipal, research and educational institution etc. A recreational pilot is considered to be an operator as well. At the time of project launch the system was considered for professional operators/pilots only, the recreational pilots have, therefore, not been consulted within this work. The professional operators/pilots have contributed with feedback to presentations given at a Danish national drone forum meeting[17] November 2015 and various other conferences and workshops during the past year. The drone operators participating in the experiment were invited to a half-day workshop described in section 5.2. At the workshop, via subsequent contact during the experiment and via the web based log described in section 5 the operators provided valuable feedback. Below is listed the feedback relevant to the system design:

Some drone operators are concerned about the risk of drone or payload malfunctioning due to installation of an external device on the drone. Their concerns are related to both the risk of crashing and the potential liability issues between drone producer, vendor, drone pilot and the producer and vendor of the external device.

Some drone operators are concerned about privacy from both a commercial and personal standpoint. As stated in section 1.1.2 privacy concerns are outside the scope of this project, however the system should be designed to support the decided level of privacy.

As discussed in section 5.4 when conducting a drone flight, the pilot already has a number of things to attend including but not limited to the task, risk assessment, drone and payload preparation and operation, communication to other stakeholders etc. The checklists are already long, and the DroneID will add more complexity to the operation. A simple user interface requiring as little attention by the pilot as possible is therefore imperative.

The device should be designed for mounting outside the fuselage on small fixed wing drones creating as little aerodynamic drag as possible. One example of installation on a small fixed wing drone is the senseFly eBee depicted in figure 16.

[17] https://www.trafikstyrelsen.dk/DA/Luftfart/Forum/Droneforum.aspx

3.1.3 The public perspective

At the time of project launch it was expected that the DroneID system would not be accessible to the general public due to privacy concerns. Representatives of the public have, therefore, not been consulted within this work.

As the project has progressed and more knowledge has been acquired it has become apparant that there may be advantages to providing the public access to a subset of anonymized information about drones flights. In cases where citizens observe drone activity near private property, gardens, beaches etc. the citizen may have an interest in knowing whether the observed drone activity is registered and authorized.

This information could be provided by an app in a way similar to the information presented about manned aircrafts by e.g. the FlightRadar24[18] app. In addition the app could be used for reporting unauthorized drone flights by submitting a picture, the geographical position and other relevant data to the relevant authority. This could be conveyed in a simple manner to the public: If an observed drone is listed in the app, it means that the drone flight is registered and authorized and that the drone is being tracked. If the drone is unlisted or if the drone behaviour seems suspicious then the public is encouraged to report this via the app.

This functionality may mitigate the concerns stated in section 6.1.1 about an increasing number of inquiries from citizens concerning drones.

3.2 Use cases

This section deals with the interaction between users and the system. Use cases for the drone pilots are discussed in section 3.2.1, drone pilots in section 3.2.2 and the public in section 3.2.3. The use cases present only the most relevant interactions and leave out interations for administrative purposes etc. For the presented use cases only the typical flow of operation is discussed, special conditions such as system malfunctioning etc. are not included.

3.2.1 Drone pilots

The drone pilots interaction with the system may be divided according to the stages of flight: flight planning, preflight, flight and postflight. A use case is defined for each of these stages, as follows.

Use case: Flight planning

- **Primary actor:** Drone pilot
- **Secondary actors:** Local authority
- **Level:** User
- **Description:** The flight planning takes place well in advance of the flight and does usually not involve the physical drone aircraft except for keeping up with

[18] http://flightradar24.com

regular maintenance tasks, reconfiguration of aircraft and/or payload etc. The drone pilot plans the flight focusing on objectives to be achieved during the flight, the flight time and location etc. are determined.

The current regulation in Denmark states that when a professional pilot wishes to conduct a flight within a Danish city, the pilot must notify the local police at least 24 hours in advance. This is considered part of the flight planning.

It has been discussed between the public authorities and agencies involved in this project if this notification or submision of a flight plan to the system will be required if the drone is equipped with a DroneID providing updated information about the drone position. The relevance may depend on the location, e.g. inside vs. outside urban areas.

- **Flowchart:** Figure 1 shows a submission procedure for a flight plan in advance of the flight.

Use case: Preflight

- **Primary actor:** Drone pilot
- **Secondary actors:** None
- **Level:** User
- **Description:** Preflight procedures takes place immediately before takeoff and are described in Figure 2. Alternatively, in a scenario where no prior flight plan is required, the system may validate the current time and position against static and dynamic limitations of flight.
- **Flowchart:** Figure 2 shows a standard preflight procedure.

Use case: Flight

- **Primary actor:** Drone pilot
- **Secondary actors:** None
- **Level:** User
- **Description:** See Figure 3. Flight is defined as the time from drone aircraft takeoff to landing.
- **Flowchart:** Figure 3 shows an ongoing flight validation procedure while in flight.

Use case: Postflight

- **Primary actor:** Drone pilot
- **Secondary actors:** None
- **Level:** User

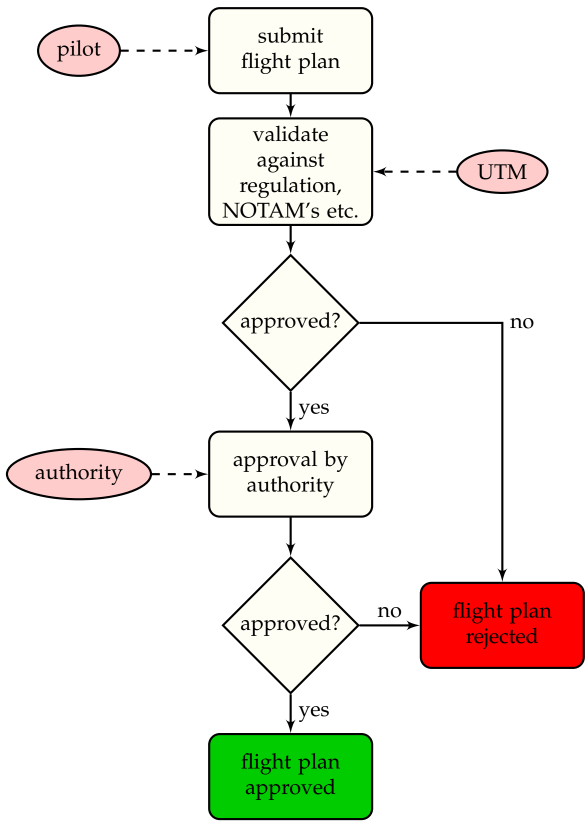


Figure 1: *Flight planning procedure example. The pilot submits a flight plan defined by informations such as purpose, pilot, drone aircraft, flight date and time, flight location defined by a geographical polygon etc. The flight plan is first validated by the UTM system against static and dynamic limitations of flight (rules, regulations, NOTAM's etc.), followed by an approval by the local authority. An alternate procedure would be to approve the flight plan upon validation by the UTM system, and then the authority may subsequently rewoke the approval if needed.*

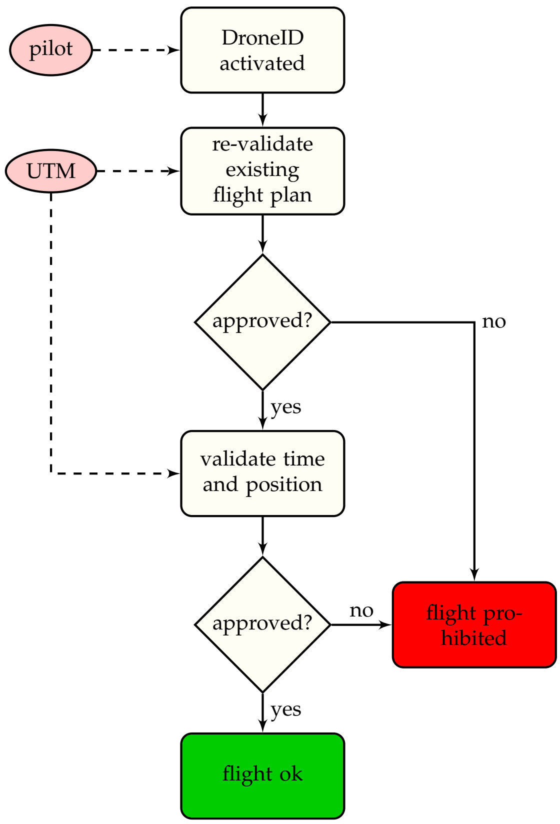


Figure 2: *Preflight procedure example. The pilot places the drone on the takeoff location and activates the DroneID. The DroneID then acquires a geographical location and establishes a connection to the UTM system, which takes a couple of minutes. The UTM system then re-validates the flight plan against static and dynamic limitations of flight. If OK the UTM system validates the flight based on the current time and position of the drone provided by the DroneID. The status of flight approval is then communicated to the pilot.*

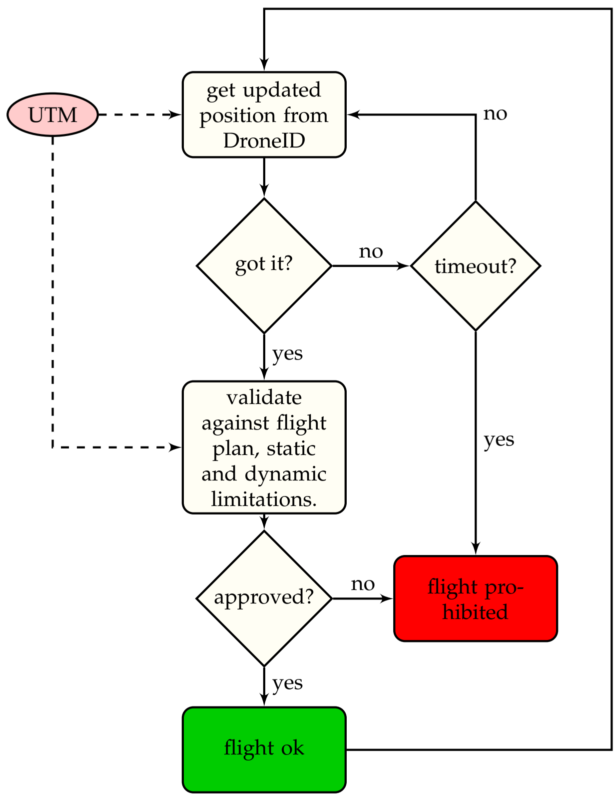


Figure 3: *Flight procedure example. While airborne the system continually receives the drone position from the DroneID. The current time and position of the drone is validated against a submitted flight plan and static and dynamic limitations of flight. Any change of flight approval status is communicated to the pilot as instructions such as "Drone altitude too high" or "Drone inside area currently restricted by NOTAM" etc. Breach of prohibited flight areas are communicated to the respective authorities.*

- **Description:** Postflight procedures takes place immediately after landing. The pilot indicates via the DroneID that the drone is on the ground either because the flight is concluded or temporarily due to a battery exchange etc. Alternatively the DroneID may sense this by monitoring drone movements and vibrations either via a connection to the drone flight controller or using built-in sensors.
- **Flowchart:** None

3.2.2 Authorities

Use case: Drone flight overview

- **Primary actor:** Authorities
- **Secondary actors:** None
- **Level:** User
- **Description:** The authorities such as the police may interact with the system for the purpose of monitoring drone flights in areas of interest. The system provides a map-based overview showing drones that are currently or have recently been operating in the area. The authorities may extract relevant information for a particular drone such as the drone type, contact information on the pilot etc. If a flight plan has been submitted, the details of this will be available as well.
- **Flowchart:** None

Use case: Inquiries from citizens regarding drone observations

- **Primary actor:** Authorities
- **Secondary actors:** Citizen
- **Level:** User
- **Description:** As described in Section 3.1.1 the police expects a significant amount of inquiries from citizens who have observed a nearby drone. An inquery may be presented directly by the citizen which is covered by the *Drone flight overview* use case.
- **Flowchart:** Making an inquiry via the system is illustrated in Figure 4.

Use case: Flight plan submission

- **Primary actor:** Authorities
- **Secondary actors:** Drone pilot
- **Level:** User

- **Description:** See Figure 1: when the system includes submission of flight plans, the authorities will be taking part in the approval process.
- **Flowchart:** See Figure 1.

3.2.3 The public

Use case: Drone observation

- **Primary actor:** Citizen
- **Secondary actors:** Authorities
- **Level:** User
- **Description:** See Figure 4: as described in Section 3.2.2 citizens may observe a nearby drone and have doubts whether the flight is legal, and use the system to verify the drone flight legality.
- **Flowchart:** Figure 4 shows a citizen using the system to verify the legality of the drone flight and eventually reporting this to the authorities.

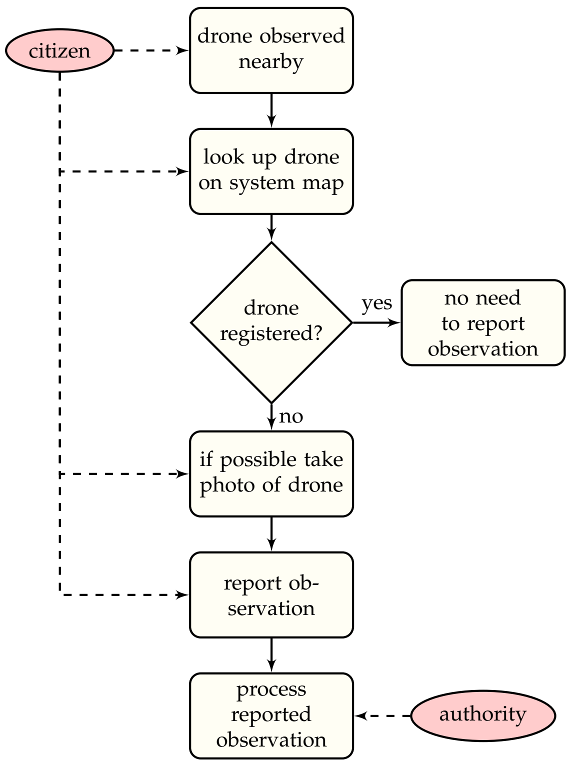


Figure 4: *Drone observation example. When a citizen observes a nearby drone and is in doubt whether the flight is legal, the citizen may look up the drone on a map provided by the system (with limited information available as described in section 3.1.3). If the drone appears on the system map, it means that it is registered and thus the authorities are already informed about the drone flight. If not, the drone flight may be illegal, and the citizen is encouraged to report the observation to the system. Observations reported by citizens are forwarded to relevant authorities. Multiple reports may be submitted by different citizens which will provide a more complete overview to the authorities.*

3.3 System specification

Based on the user perspectives described in section 3.1 and the use cases defined in section 3.2 a set of design requirements and design goals have been defined. These are listed in the following sections.

3.3.1 Design requirements

The design requirements listed below are hard requirements in the sense that the system must meet the requirements.

1. The system must be based on a national UTM service containing information about planned, current and historical drone activities.

2. Information about a drone activity must include at least the the pilot and/or drone identification, pilot contact telephone number, the type and class of the drone, type of operation, drone flight location and time period, and polygon describing the maximum operation area.

3. Information updates must be transmitted at regular intervals while the drone is airborne. Results from the field experiment described in section 5 suggest that moving drones should update approximately each second to maintain a clear relationship between the drone and a map when viewed by an observer. The updated information must include at least the pilot and/or drone identification, the drone position and height.

4. To avoid requirements for dedicated ground based hardware and the associated cost hereby, all users (authorities, operators/pilots and the public) must be able to access the UTM information via internet using smartphones, tablets and computers.

5. In addition to drones where the manufacturer has implemented compliance to specifications given by the system, the system must also be capable of supporting drones that do not comply for reasons such as production before the specifications were available or drones assembled using third party modules and components.

6. Any hardware required to be implemented or retrofitted on drones must fit multirotors and fixed wing drones between 250 g and 25 kg (section 1.1.1).

7. To address the stated privacy concerns and to support the decided level of privacy, all data transmitted between drones and the UTM as well as between users and the UTM must be protected by end to end encryption. Updates transmitted from the drones must use rolling code or similar means to ensure protection against identification or spoofing by replay based on eavesdropping of the encrypted data.

8. In order to provide the desired UTM services, data about drone flights, pilots, operators etc. will be stored for post-processing and historical reference. The ownership of these data must be well defined, and proper processes for deletion of outdated data must be implemented.

3.3.2 Design goals

Below are listed a number of additional design goals. The design goals are not hard requirements but the design and development process should seek to optimize these.

1. The expenses for running the UTM will most likely be charged to the operators which may or may not include recreational drone owners. The expenses for required hardware and running costs should therefore be minimized.
2. The usability depends on the availability and reliability of the system. The design should therefore focus on timely, accurate and reliable data as well as a high system uptime.
3. The national UTM is expected to be extended with many new services and functions over time. The UTM architecture should therefore be designed to meet a significant increase in complexity.
4. The primary purpose of the system is implementation as a national solution for Denmark, however where possible the system should be designed towards use in other countries in the EU. The system design should follow existing EU standards where applicable.
5. To extend the system lifetime, components and modules used should be evaluated with respect to future availability.

3.4 Architecture

Based on the specifications outlined in section 3.3 a system architecture was defined. This section describes the architecture and explains the design choices made.

The design requirement of providing drone position and altitude updates at regular intervals while the drone is airborne, requires either the drone or a ground based tracker to transmit this information to the UTM. Drones are usually not tracked by ground based equipment, and thus the drone must transmit it's position, altitude and other relevant values using some means of wireless communication. The two generic solutions considered in this work are:

1. The drone transmits a local beacon signal which is then received by a nearby receiver and relayed to the UTM via internet. This is depicted in figure 5 by the green arrows.
2. The drone communicates directly with the UTM via internet using a radio network infrastructure. This is depicted in figure 5 by the blue arrow.

Either of the two solutions require a device on the drone capable of transmitting the information. Section 3.6 describes this device in more detail and deals with the possibility of integrating the device into the drone hardware vs. using an external device installed on the drone. The signalling properties of the two solutions are described in the following sections 3.4.1 and 3.4.2.

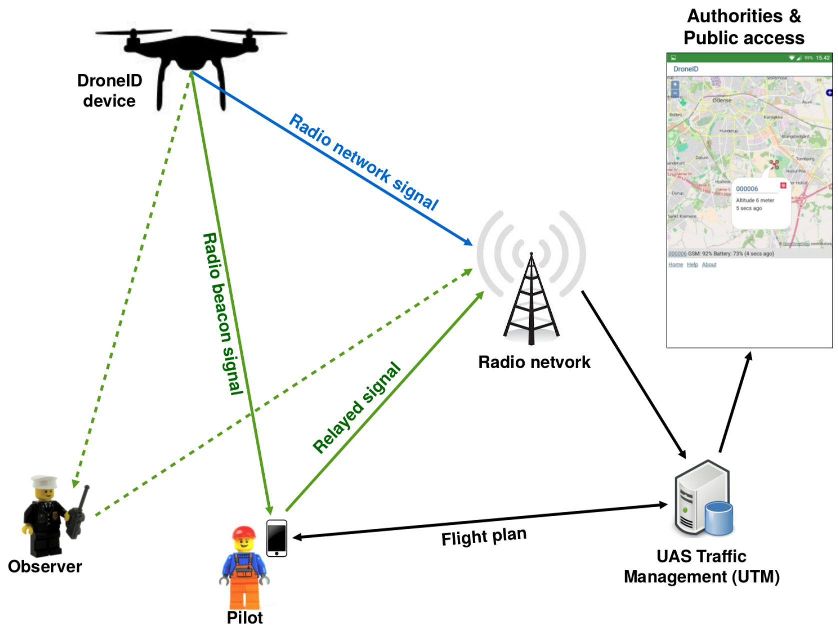


Figure 5: *DroneID system architecture. The green arrows illustrate the information path for a local radio beacon signal transmitted from the drone and relayed to the UTM via the pilot or an observer. The blue arrow illustrates information transmitted directly from the drone to the UTM via a radio network infrastructure.*

3.4.1 Local beacon signal

Transmitting a local beacon signal from a drone requires a predefined frequency or frequency spectrum. The use of the radio frequency spectrum is regulated in most countries, in Denmark this is managed by the Danish Energy Agency (DEA)[19]. The choice of frequency is thus governed by both the regulation, the physical properties of radio frequencies such as antenna size and signal attenuation as a function of distance and obstacles near or within line of sight, and the risk of causing interference with other radio communication systems on the drone.

The *Very High Frequency* (VHF) band is defined as frequencies ranging from 30 MHz to 300 MHz. Upon consultation DEA has assessed that it will be practically impossible to find a spectrum within the VHF band to be used exclusively for drones, since everything has been allocated for other purposes.

The *Ultra High Frequency* (UHF) band is defined as frequencies ranging from 300 MHz to 3 GHz. The DEA has assessed that there are some possibilities within UHF band which could be explored. Though the UHF band is not as "crowded" as the VHF band, it will still be very difficult to find a spectrum to be used exclusively for drones. One important reason is that Denmark has several neighboring countries and allocating a nationwide spectrum requires coordination with each neighboring country in order to avoid interference problems. A possible solution to this is to use different frequencies depending on the region within Denmark, however this will

[19] http://www.ens.dk/en/Telecom-and-Spectrum

complicate the design and development of the DroneID device and receivers on the ground.

An alternative to allocating a frequency spectrum for drones is to use one of the frequency spectrums already allocated to a specific purpose. These radio frequency spectrums are listed in the announcement *Bekendtgørelse om anvendelse af radiofrekvenser uden tilladelse samt om amatørradioprøver og kaldesignaler m.v.*[20] As mentioned in section 1.2.2 a working group under the organization UAS Denmark assessed the applicability of some radio frequency spectrum [11], and especially DECT showed an impressive range when used in areas without obstacles between the drone and the ground based reciever.

Most of the radio frequency spectrums require a dedicated receiver. This does to some extent conflict with the design requirement of limiting the requirements for extra equipment for ground based monitoring described in section 3.3.1. The only frequency spectrums typically supported by tablets and smartphones are Wifi and Bluetooth, both of which operate in the 2.4 GHz band. If one of these spectrums are used, the risk of potentially causing disturbance of Command and Control (C2) links operating within the same band should be investigated.

If the device is integrated into the drone by the manufacturer, it may be possible to use an existing drone telemetry link to transmit the beacon signal down to the pilots control unit or Ground Control Station (GCS) and from there relay the signal to the UTM. This will, however, prevent other actors on site from monitoring the beacon signal independent of the pilot, and this may be a problem is the signal is not properly relayed to the UTM because of lack of network coverage, technical issues or the pilot prevents this deliberately.

If similar systems are to be deployed within the EU it probably makes sense to initiate the process of allocating an EU wide radio frequency spectrum for drone C2 and UTM. The process can however be expected to take a number of years. Recent examples of allocation of radio frequency spectrums across the EU member states are the *Spectrum Requirements for Narrow band Point-to-Multipoint (nP2M) system operating in the 430-470 MHz frequency range* [21] and the *Intelligent Transport Systems (ITS) operating in the 5 GHz frequency band* [22]. A similar initiative of allocating a spectrum for UAS Control and Non-Payload Communications is currently being pursued by NASA [16].

The concept of using visible or infrared light as a local beacon signal was considered during the design of the system architecture. One example is described in section 1.2.4 using color LED's to signal a blink sequence which can either be remembered or captured and decoded by a smartphone app. A major advantage is that while the use of the radio spectrum is regulated in Denmark and many other countries, the infrared and visible frequency spectrums are not. There are, however, a number of disadvantages which lead to the exclusion of this concept: Direct line of sight is required to receive a light signal; Light signals may be difficult to monitor from a distance, especially in bright sunlight; Visible light may disturb camera payloads; A camera must be pointed towards the drone in order to receive the signal.

[20] `https://www.retsinformation.dk/Forms/R0710.aspx?id=169535` appendix 5.
[21] `http://www.etsi.org/deliver/etsi_tr/103100_103199/103102/01.01.01_60/tr_103102v010101p.pdf`
[22] `http://www.etsi.org/deliver/etsi_es/202600_202699/202663/01.01.00_50/es_202663v010100m.pdf`

In addition to the GBSAA functionality described in section 3.5 a local beacon signal has the added benefit of being readable by other nearby drones. This enables the drones to receive information for direct Sense And Avoid (SAA) without requiring the UTM in the loop and thus eliminating time delays.

The experiments concerning local beacon signal transmission is in this work carried out by the industrial companies associated with the project. This is described in section 6.2.2 and 6.2.3.

3.4.2 Radio network infrastructure

Communicating directly with the UTM via internet from the drone requires access to a radio network infrastructure which may be ground based or satellite based.

Examples of satellite based internet access infrastructures are Iridium, Inmarsat and Globalstar. For Iridium and Inmarsat there are Original Equipment Manufacturer (OEM) modules available such as the Iridium 9603 and the Orbcomm OGi which provide feasible Size, Weight and Power (SWaP) properties for drones weighing just slightly more than 250g. Globalstar provides a STX3 Simplex Satellite Transmitter capable of transmitting one-way data messages that would probably fit onto a 250g drone. Despite the availability of suitable OEM modules the use of satellite based communication has been disregarded in this work due to the higher cost of hardware and subscription compared to ground based networks.

In Denmark the obvious choice of a ground based radio network infrastructure would be GSM network based data transmission. Cities do in general have a good coverage and most rural areas have a reasonable coverage as well, however the coverage may differ based on the service provider and the technology used for data transmission. The available techologies in increasing order of data transmission rate and generation are GPRS, EDGE, 3G, HSDPA, HSPA+ and LTE. Due to the very low bandwidth required by the system, it makes sense to choose among the earlier generations of technology to optimize for power consumption and cost of the module. It should be expected though, that the service providers will begin phasing out the GPRS and EDGE within a few years.

Another interesting contender within ground based radio network is LoRaWAN, a Low Power Wide Area Network (LPWAN) specification intended for wireless battery operated Internet of Things (IoT) in regional, national or global network.[23] As an example, the Microchip RN2483 transceiver module provides >15 km coverage at suburban and >5 km coverage at urban area enabling a reasonable simple network infrastructure.[24] The bit rate is up to 5 kbps and the weight of the module about 2 g. LoRaWAN is a quite new technology, service providers are currently establishing nationwide LoRaWAN in some countries, but this is not yet available in Denmark. Examples of using LoRaWAN for drone applications have not been found.

[23] https://www.lora-alliance.org

[24] http://ww1.microchip.com/downloads/en/DeviceDoc/50002346A.pdf

3.5 UTM service

The purpose of UTM is to enable safe low-altitude civilian operation of drones. The overall functionality is to provide the authorities information about planned and ongoing drone flights as well as provide drones and drone pilots information needed to maintain separation from permanent or temporary no-fly zones and other aircrafts etc.

Components often discussed within UTM are registration of drones, operators and pilots; registration, validation and authorization of flight plans; drone identification; tracking of drone flights; static geofencing of no-fly zones such as airports, prisons, nature concervation areas etc.; dynamic no-fly zones typically specified by NOTAM. UTM is also considered a potential component in future drone GBSAA systems [2] which becomes especially relevant when considering BVLOS flights and a high level of autonomous control. UTM is still in early development, section 1.2 describes some of the current activities.

As stated in section 1.2.5 and 2 the primary focus of this work is the design and proof of concept demonstration of an external DroneID device communicating with a UTM service. The UTM service developed and used in this work is therefore experimental only, and this report does not propose a system design of the UTM service beyond what is described in section 3.1.

3.6 DroneID device

As presented in section 3.4 the architecture requires that drones have the ability to communicate with the system for transmission of position, altitude etc. The hardware and software providing this functionality is named the *DroneID device*.

The system design requirements in section 3.3 specify that the DroneID device functionality may be integrated into the drone, if the manufacturer ensures compliance to the DroneID device specifications. Drones not suporting this functionality will need to have an external DroneID device installed. Inherently this is currently all drones as no specifications have been published yet.

In this work the focus is on designing and developing a first prototype of an external DroneID device. Compared to implementation by drone manufacturers the external DroneID device will be more complex, yet the overall functionality and thus the design is the same.

Figure 6 shows the system diagram of an external DroneID device. The geographic positioning is obtained via a Global Navigation Satellite System (GNSS) receiver supporting common systems such as Global Positioning System (GPS) and GLObal NAvigation Satellite System (GLONASS). The onboard sensors would include a barometric altimeter to improve the accuracy of the altitude estimation, an Inertial Measurement Unit (IMU) to estimate orientation and vibrations of the DroneID device and hereby assess the current state of the drone (stand-by, takeoff, in flight, landing). The radio communication module providing the interface to the system may be either a local beacon signal (section 3.4.1) or a radio network infrastructore module (section 3.4.2). Both the GNSS and the radio module have built-in antennas. The device is powered by an internal battery connected to a circuit for charging and battery

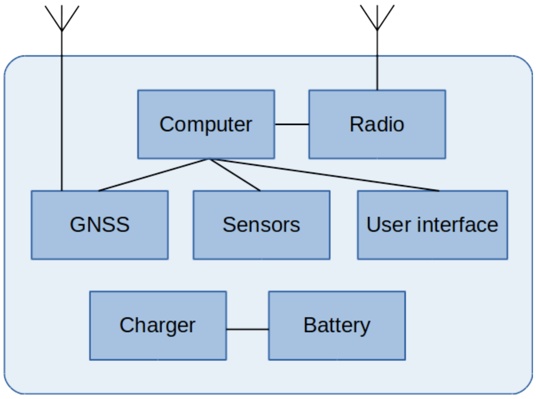


Figure 6: *System diagram of an external DroneID device. The computer is connected to a radio module for wireless communication with the system, a GNSS for absolute positioning, a user interface to enable operation of the DroneID device by the pilot, and sensors supporting the position estimation, user interface and electronics. The device is powered by a built-in battery which is recarged via an internal charging circuit.*

protection. The charging circuit receives power via an external charging connector.

3.6.1 Design requirements

Below are listed design requirements for the external DroneID device. They extend and add to the system design requirements in section 3.3:

1. **Independent device:** To support the wide variety of drones on the market, the DroneID device must be fully self-contained, the installation must not have any requiremens concerning power supply, radio communication, GPS positioning etc. via the drone.

2. **Weight limit:** Section 3.3 states that the minimum weight of a drone supposed to use DroneID is 250 g. The weight of an external DroneID device must reflect this, and the weight of the DroneID should therefore be less than 25 g.

3. **Ingress Protection Rating:** The DroneID device must be operable under normal environmental conditions. Following the international standard IEC 60529 an external DroneID device must be rated at least IP53 meaning that it is protected against dust and spraying water at any angle up to 60 degrees from vertical.

4. **Range:** The range of the DroneID should support all normal operations withing Line Of Sight (LOS). If a local beacon signal (section 3.4.1) is used, the DroneID device must therefore support a range of at least 500 m to the pilot or an observer (figure 5).

3.6.2 Design goals

In addition to the design requirements listed in section 3.6.1 the following design goals should be taken into consideration while designing the external DroneID device:

1. **RF noise:** To the extent possible design guidelines for reducing Electromagnetic Interference (EMI) should be followed. The DroneID device is typically installed in close proximity to the drone flight controller, navigation sensors, C2 link and other vital modules and components. In addition the DroneID device should be protected against external interference from the drone electronics such as telemetry and video link transmitters etc.

2. **SWaP:** To minimize the impact on the drone operation and flight the DroneID design should be optimized with regards to SWaP.

3. **Aerodynamics:** When installed outside the aircraft fuselage on a fixed wing drone, the shape of the external DroneID device will affect the drone flight capabilities. The device exterior should be designed to minimize this effect.

4. **Installation:** The external DroneID device must support installation on a wide variety of multirotor and fixed wing drone platforms. The device should be designed for flexible and easy installation and use. The design should also consider easy access to the user interface and charging connector.

5. **Usability:** The user interface must be very simple and intuitive. Any LED's and buttons on the external DroneID device must be easy accessible while the device is installed on the drone. A pilot conducting a drone flight has a wide range of tasks to attend to (drone flight, payload operation, the task at hand, safety etc.) and will thus have only few resources left for monitoring and operating a DroneID device. The importance of this was clearly identified during the field test (section 5.4).

6. **Telemetry:** In addition to the identification number, geographical position and altitude, the DroneID device should be able to transmit further telemetry data such as logged minimum/maximum altitude, velocity, radio RSSI level (section 4.3.2) etc.

3.7 Discussion

In this section a system design for drone identification and tracking in Denmark has been proposed.

The DroneID system architecture described in figure 5 supports communication via either a local beacon signal (section 3.4.1) or a radio network infrastructure (section 3.4.2). The choice between the two depends on the implementation of the regulation. As an example if only drones operated within cities by professional drone operators are to be tracked, then the radio network infrastructure may possibly be the best solution. If all drones used for professional and leisure activities must be tracked both in cities and rural areas, the radio network infrastructure may not be feasible with regard to radio coverage, the DroneID SWaP and the financial expenses. The local beaon signal may therefore prove to be a better solution. Some combination of the two solutions is also a possibility, eg. using radio network infrastructure for professional operations/inside cities and local beacon signal for leisure use/in rural areas.

At the time the experiments in this work was conducted, it was expected that the drone identification and tracking would only be relevant for professional drone operations within cities. The main focus in this work has therefore been on the radio network infrastructure (section 2). The experiments are based on GPRS due the availability of low-cost modules. The choice of technology generation is not considered important to the project aim. Companies involved in the project has demonstrated succesful tests of local beacon signals, this is documented in section 6.2.

The submission of flight plans prior to drone flights presented in section 3.2 is expected to be a valuable operational addition to the drone identification and tracking and will form a base for future extensions of the UTM service. It is assessed, however, that the infrastructure to support submission, validation and approval of flight plans can be implemented using well known web and app techonologies. This topic is therefore not included in this work.

Figure 7: *The DroneID device developed in the fall 2015. The external GPS antenna is described in section 4.3.3.*

4 DroneID device

In this section the external DroneID device (figure 7) developed in the fall 2015 for the field experiment is documented. Keeping in mind the aim of this report the documentation has a high focus on choices made, the reasoning behind and the experiences obtained during performed tests and experiments. Where relevant some of the documentation is very detailed in order to facilitate future development of DroneID devices.

4.1 Mechanics

The external DroneID device prototype consists of a main Printed Circuit Board (PCB), a lithium polymer battery, a GPRS PCB antenna, a 3D printed casing and an external GPS antenna. The prototype electronics measures 22x38x11 mm. The exterior dimensions of the casing are 38x46x19 mm. Table 1 lists the weight of the prototype.

Part	**Weight [g]**
Casing	6.6
Main PCB	7.0
GPRS antenna	0.9
GPS antenna	3.9 - 5.7
Battery	9.0
Total	*27.4*

Table 1: *Weight of the prototype parts. The GPS antenna is provided with varying length of the feedline depending on the drone. The total weight is based on the shortest feedline used.*

The prototype is designed for a radio network infrastructure (GPRS) rather than a local beacon signal (section 3.7). This adds to the size and weight of the main PCB, the GPRS antenna and the Battery listed in table 1.

Figure 8: *The prototype casing.*

It is expected that further development will result in a decrease of both size and weight: The current main PCB was sized similar to the battery size rather than size requirements of the components; software improvements may bring down requirements for battery capacity; a nano-SIM (4FF) card was used, but a smaller M2M embedded-SIM (eUICC) also exists; as described in section 4.3.3 the GPS antenna connector used (SMA) was chosen based on its durability, but smaller and lighter connectors are available; the external GPS antenna may be replaced by an internal antenna.

Supposing that the same DroneID device functionality was integrated into the drone by the manufacturer, this would lead to a significantly lower weight. In this configuration a local beacon signal (section 3.4.1) may make more sense as the manufacturer may be able to include the beacon functionality into an already available telemetry radio. But even if the GPRS solution was chosen, only the weight of the main PCB and the GPRS antenna listed in table 1 would have to be included. The main PCB would be somewhat lighter as the computation may possibly be handled by the drone flight controller, and elements such as the GPS module, power supply, charging circuit etc. will probably be redundant. Based on experience from the current prototype the extra weight added to the drone by an integrated DroneID device functionality is estimated to be about 3-5 g.

4.2 Casing

A casing (fig. 8) was designed for the prototype to support installation on different drone platforms and to protect the electronic components against the environment. It was designed with flanges to support mounting on the drone. The casing has an opening for the GPS antenna connector which also supports the main PCB. The charging connector and the operators button is placed on the main PCB beneath a casing lid. Since the operator should access the charging connector before flight and the button multiple times during flights, the lid is designed to be removed without use of tools.

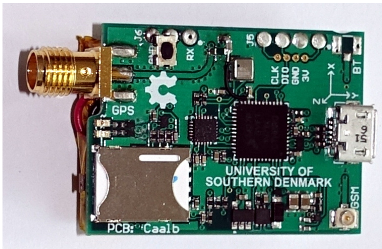
The casing was printed in a Polyamide (nylon, PA) material on a printer using the Selective Laser Sintering (SLS) technique. The result was a robust casing which endured the experiment described in section 5 without problems. Suggestions for improvements identified during the project are described below.

The prototype casing was not properly sealed against rain and moist. LED's must be clearly visible and buttons must be operable without removing a lid thus compromising the weather sealing. This is documented in section 3.6.1.

As mentioned in section 3.6.2 some fixed wing drones do not have interior space for installing the external DroneID device. It should therefore be aerodynamicly shaped to support installation on the outside of the aircraft fuselage. A possible solution would be to design a minimal aerodynamically shaped DroneID device and an external mount with flanges to support easy installation on e.g. multirotor drones. The locking mechanism could be a click-in, velcro or a magnet.

4.3 Electronics

The external DroneID device electronics consists of a main PCB, an external GPRS antenna, an external GPS antenna and a Lithium Ion (Li-ion) battery pack. This corresponds to the system diagram shown in figure 6: The main PCB contains the processor, radio, GNSS, sensors and user interface modules, while the charging circuit is built into the battery pack. Figure 9 shows the DroneID main board and GSM antenna. Figure 10 (b) shows the GNSS antenna.



(a) DroneID main PCB

(b) DroneID GPRS Antenna

Figure 9: *The DroneID device main PCB and GPRS antenna. The other side of the PCB contains the GPS/GPRS module and the Li-ion battery.*

4.3.1 Processor

The processor used for the DroneID device is a Kinetis KL27 Microcontroller [25] (MKL27Z256VFT4) which is a 48 MHz ARM Cortex®-M0+ with 256 KB Flash, 32 KB SRAM and 16 KB ROM.

The L series is an ultra low power series that allows the MCU to enter a deep sleep mode which has a power consumption of 1.96 μA. It has the required peripherals for sensors and communication used by the external DroneID device. In addition it has a USB peripheral which may be useful for firmware updates and data logging.

Free development tools based on open source software such as Eclipse, GNU Compiler Collection and GNU Debugger are available. Freescale also offers the free plugin software Processor Expert (PE) which uses the Kinetis Software Development Kit (KSDK) and user input to instantiate the Hardware Abstraction Layer, USB-drivers

[25] http://www.nxp.com

and Real Time Operating System (RTOS). This has the potential to decrease the development time significantly, but in this work it turned out that PE was not capable of instantiating all peripherals, because the KSDK was incomplete for the selected processor model. This resulted in a significant development time overhead.

Being the smallest ARM processor available with minimal power requirements and at a low cost made this processor the preferred choice. During the development it was learned, however, that this processor is not an ideal for the DroneID device, at least not until the device has been significantly product matured: The lack of hardware numeric processing abilities is a limitation to processing sensory data; when adding a RTOS and a USB library the memory size becomes quite limited; adding encryption capabilities are expected to increase the processing power problems.

4.3.2 GPRS

A SIM808 GSM, GPRS and GPS module provides the GPRS functionality. An off-the-shelf GSM PCB antenna GSMPB-1[26] was chosen to decrease the development time. Figure 9 (b) shows the antenna.

During the field experiment described in section 5 problems with limited GPRS coverage occured when used in some rural areas. At this time the DroneID device software did not support monitoring the Radio Signal Strength Indicator (RSSI) and no experiments to evalate the antenna performance were conducted. It is suggested that in future work RSSI should be transmitted by the DroneID device to let the UTM continously build and update coverage maps.

4.3.3 GPS

The GPS receiver functionality is provided by the SIM808 module. It turned out that the firmware version installed in the modules received was not properly documented, and contact to the company support proved to be a challenge.

The module interface offers two methods for obtaining the position, altitude and satellite information: data pulling or via a publishing service. For the DroneID device it was chosen to use the publishing service to receive the updated position data without extra delay. For some reason unknown to the authors while the publish service is enabled and transmitting GPS data at 1 Hz it regularly shifts to transmitting data with a delay up to 30 s. This problem has been mitigated in software by restarting the module on the fly when the problem is detected.

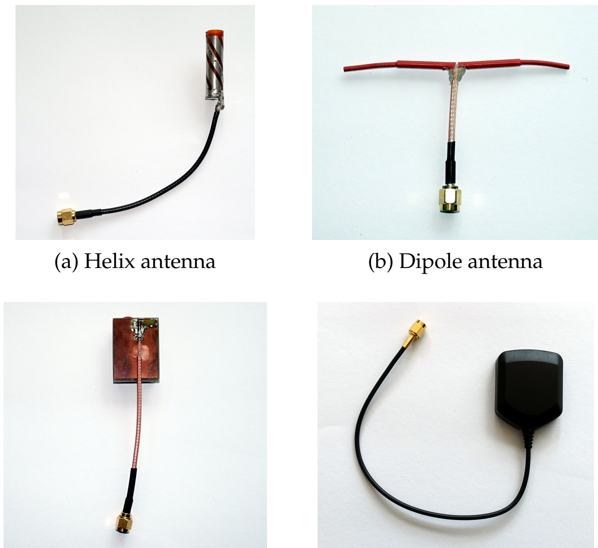
It was decided to use an external GPS antenna for this prototype. The reasoning behind this was mainly the project time constraints. As described in section 5.2 the DroneID device will in most cases be installed on the side or below the drone body, and there was no time to perform prior tests of onboard GPS antenna efficiency when installed at these locations. A SMA connector was thus added which allows the external GPS antenna to be installed on top of the drone body next to but without shading or in other ways interfering with the drone GNSS antenna. The SMA connector is somewhat heavy and bulky compared to smaller coax connectors but it is

[26] http://rfsolutions.co.uk

expected that installation of the antenna by the pilot, sometimes in the field during pre flight check requires the connector to be reasonable rugged.

The signal transmitted by GPS satellites uses Right Hand Circular Polarization (RHCP) in order to avoid signal loss from polarization mismatch and to mitigate the problems occuring by signal multipath: The first reflection of a RHCP signal will have Left Hand Circular Polarization (LHCP) and will thus be strongly rejected by a RHCP antenna. The second reflection will be RHCP but due to the two reflections this signal will be significantly weaker.

A GNSS antenna commonly used by drone vendors is a ceramic passive or active RHCP patch antenna. The antenna footprint is typically from 10x10mm up to 70x70mm including a metal ground plane. Another antenna seen on drones is the RHCP Helix antenna which has a smaller footprint but protrude above the drone body. If the low triviality threshold discussed in section 1.1.1 is introduced, then the low-cost and low weight monopole chip antennas will expectedly be used on some drones as well. Chip antennas have a footprint of only a few mm's but their performance depends on the size of the ground plane which should have a size comparable to the ceramic patch antennas [17].



(a) Helix antenna

(b) Dipole antenna

(c) Chip antenna

(d) Patch antenna

Figure 10: *The four GPS antennas used in the experiment comparing the SNR: The Helix antenna origins from a Garmin GPS 60 receiver; the Dipole antenna was produced for the DroneID device; the Chip antenna is a ublox product soldered to a ground plane according to design recommendations; the Patch antenna is a ublox product.*

The GPS antenna used for the external DroneID device is a half-wave dipole cut to the length of 0.095m corresponding to the GPS L1 frequency of 1575.42 MHz. The reasoning behind this choice is the low-cost, low weight, low footprint and the flexibility with regards to installation on different drone types and models that a dipole antenna provides. Since the dipole (like the monopole) antenna has a Linear Polarization (LP) it will only receive the in-phase component of the RHCP signal.

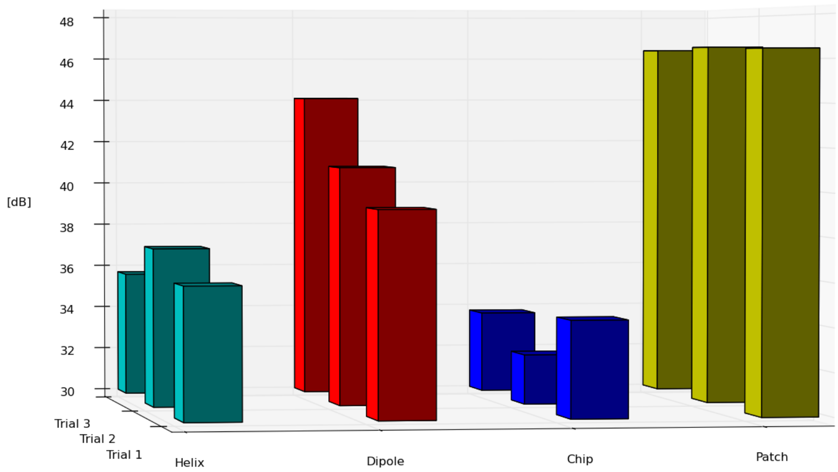


Figure 11: *Results of the GPS antenna SNR comparison experiment. The comparable SNR for the four antennas (marked by distinct colors) in three trials are depicted on a logaritmic scale [dB]. The SNR for the Dipole antenna varies significantly but it shows a higher overall SNR than the Helix and Chip antennas and a lower overall SNR than the active Patch antenna.*

The resulting Polarization Loss Factor (PLF) is 0.5 corresponding to -3dB.

To evaluate the gain of the half-wave dipole GPS antenna used in comparison to the other GPS antennas discussed, a simple experiment was conducted: The four antennas shown in figure 10 were each connected to an external DroneID device and data was sampled from all antennas for 7-10 minutes via a PC connected to the respective DroneID devices. The data was then post processed to obtain a comparable Signal Noise Ratio (SNR): The post processing algorithm calculates for each antenna the average SNR for each satellite in view. The SNR of the 6 satellites having the highest average SNR are then added and the result divided by 6. The reasoning for using this algorithm rather than comparing SNR for the individual satellites with respect to time is the dipole antenna which is linear polarized and thus may behave differently compared to the circular polarized antennas. This experiment was repeated 3 times, each time the DroneID devices were exchanged to avoid a possible bias from a potential erroneous DroneID device.

The experiment contains some uncontrollable variables: The DroneID devices were hand soldered and may thus not have the same sensitivity; The test site contained some obstacles causing a potential difference in the satellites visible to the antennas. Based on this and the described algorithm for calculating a comparable SNR the results should be considered qualitative only. Figure 11 shows the results. The comparable SNR of the dipole antenna varies significantly which is probably due to the linear polarization, still it clearly outperforms the Helix and Chip antennas. The Patch antenna containing an electronic signal amplifier expectedly shows the best performance.

It is concluded that the dipole antenna used for the DroneID device is a good solution in terms of GPS signal reception. In addition it is the antenna type which is easiest to install on the drone with regards to obtaining a clear view of the sky without obstructing the drone GNSS antenna or touching the propellers. It does however add to the total weight of the external DroneID device, and it complicates the overall installation of the device.

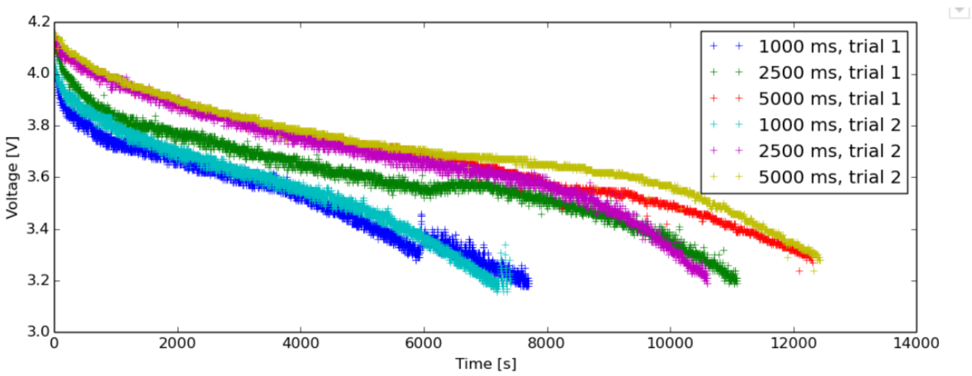


Figure 12: *Battery discharge rate experiment. The graph depicts three tests with GPRS transmission update rates of approximately 1, 2.5 and 5 seconds. The tests were repeated two times. The results show that the battery discharge rate depends significantly on the update transmission frequency. At the 1 second update rate, the battery lasted approximately 2 hours. At the 2.5 s update rate, it lasted approximately 3 hours and at 5 s update rate it lasted approximately 3.5 hours.*

4.3.4 Battery and charger modules

The purpose of the battery and charger modules are to supply power to the other modules at the external DroneID device. Section 3.6.1 specifies a design requirement that the DroneID device must have it's own power supply.

A battery pack based on Li-ion technology is used because of its high energy density and the amount of charge/discharge cycles during the battery life time. The chosen battery pack is a pouch cell with an internal safety circuit that prevents overcurrent and the State Of Charge (SOC) from exceeding the capacity of 400 mAh. The output voltage is 3.0-4.2 V.

The charger circuit is located on the main PCB. The charging input voltage via a micro-USB connector is 5.0 V. The full charging time (SOC from 0 to 100%) is approximately 3 hours.

The input voltage range of the SIM808 GSM, GPRS and GPS module is specified to 3.4 to 4.4 V. As indicated in figure 12 it typically shuts down at approx. 3.2 to 3.3 V. Other GPRS/GNSS modules may support a lower minimum voltage which will increase the operation time when using this battery pack.

During the prototype development the chosen battery capacity was estimated to be suitable for roughly a couple of hours of operation. Results from field exercise revealed a problem of low battery levels while using the DroneID device. This is partly due to the use pattern described in section 5.4 and partly because the current software version does not seek to optimize the device operation time by limiting the use of GPRS, GPS and CPU or utilize low power mode of the modules etc.

The identified problem led to further consideratons about the required battery capacity and the potential for lowering the device power consumption. Communicating via GPRS consumes signficant power, so a battery discharge experiment was conducted to quantify the power saving potential. In the experiment the battery was charged to full capacity, then the DroneID device was activated to perform the normal operation ie. transmitting updates at a regular interval to the UTM and receiving responses herefrom.

To make the experiment independent of variation of the battery total capacity a single test was conducted for each transmission update rate and then the entire experiment was repeated. Should the battery total capacity somehow decrease during the trials, this would be evident from the results. To minimize impact from other variables all trials were performed with the same DroneID prototype at the same outdoor location.

The results of the experiment are presented in figure 12. The blue graph makes a sudden jump at about 6000 s. An investigation of the data has revealed that during the jump the GPRS module seemed to buffer a number of UDP packets which were then subsequently transmitted. This is evident from the time stamp differences between the DroneID packet generation and the UTM server reception. During this buffering the battery voltage increased which is belived to be caused by the battery resting while no GPRS transmissions were conducted. It is also notable that at the trials with a transmission update rate of 5 s the device stops transmitting at a higher battery voltage. This is probably because the voltage spikes are relatively higher, when the average current is low, thus reaching the lov voltage threshold of the SIM808 module earlier.

It is evident that the GPRS transmission update rate significantly influences the battery discharge rate, and it is worth considering approaches to limit the number of updates transmitted to the UTM without compromizing the device funtionality. The system design requirements in section 3.3.1 state that a moving drone must transmit updates each second, but if the drone is hovering or moving very slowly the update interval could probably be increased to eg. 5 seconds. Also if the DroneID device supports bidirectional communication, the UTM could provide information to the DroneID device if users are actively monitoring the drone or not. When the drone is not monitored the update interval could again be increased to eg. 5 seconds.

4.4 Software

In this section the Real Time Operating System (RTOS), the software architecture and the communication protocol is described. Further details about the software can be found at the the DroneID repository. The address is listed at the beginning of this report.

4.4.1 Operating System

The DroneID v1 software uses the FreeRTOS[27] software. The reasoning for using an RTOS rather than writing software directly to the controller is the preemptive scheduler which enables a division of functionality into seperate tasks. The RTOS also provides queues, mutexes and semaphores to ease the use of variables between the tasks.

[27] http://www.freertos.org

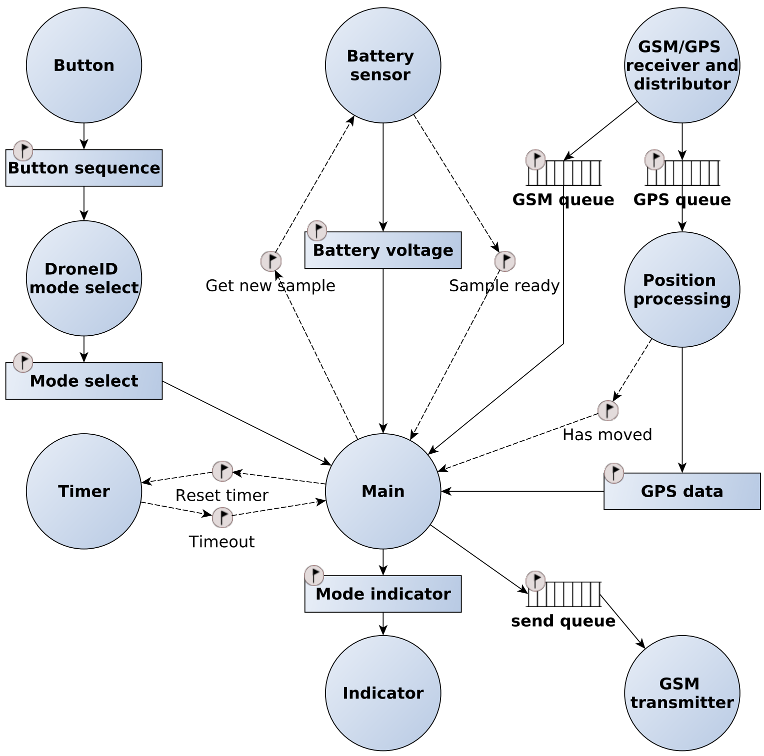


Figure 13: *Task diagram of the software for the DroneID device.*

During the development it was discovered that while the FreeRTOS license is open source, it uses the license GPLv2[28] with two exceptions. Essentially the exceptions state that the FreeRTOS source can only be distributed under the terms of the GPLv2 plus the exceptions[29] which apply to any linked module. The first exception is that the copyright holders allow users to produce a statically linked executable and distribute this under terms of the user's choice. The second exception is not relevant here. This means that it is not possible to publish the FreeRTOS source along with the DroneID v1 source which is released under the permisive free BSD 3-Clause license. Therefore the DroneID repository only contains the DroneID source, the FreeRTOS source must be downloaded seperately.

4.4.2 Software structure

A task diagram listing the different tasks of the DroneID device software is shown in figure 13. Below is a brief description of the different tasks:

Button: Read the input signal from the button and decode the press type between into three type of press; single, double and long press. When a valid press type has been read from the input it passes the information to the "DroneID mode select" task.

[28] http://www.gnu.org/licenses/old-licenses/gpl-2.0.html
[29] http://www.freertos.org/license.txt

DroneID mode select: This task basically just pushes the information on to the "Main" task and it is only kept in the software as a preparation for other sensor inputs that are not yet implemented.

Timer: The task only wakes up when it is time to transmit an updated position to the server or if the timer is reset from the "Main" task. It signals the "Main" task if it is time to transmit by passing a binary semaphore.

Battery sensor: The task sleeps until a binary semaphore is received meaning it is time to measure the battery voltage. The task starts and Analog to Digital Converter (ADC) and calculate the actual voltage from the result. When the measurement is done it passes the voltage and a binary semaphore to the "Main" task.

GSM/GPS receiver and distributor: When a new line is received via UART from the GSM/GPS module it separates the data into two different queues where the GSM data goes to the "Main" task and the GPS data goes to the "Position processing".

Position processing: The GPS data is validated and relevant data stored in buffers for the "Main" task to read them. If the DroneID device has moved more than a predefined distance then it passes a binary semaphore to the "Main" task to make it transmit a new position to the server.

GSM transmitter: Transmit the data from the "send queue" to the GSM/GPS modem via UART.

Indicator: Shows the state of the DrineID device by flashing LED's in different colors and frequencies. It signals one red flash for stop, two red flashes for connecting, fast red flashing for tracking and fast green flashing for tracking with GPS fix.

Main: This is the biggest task and it is described by the flowchart depicted in figure 14. When the device is powered on it is in stop mode and therefore waits for the pilot to put it in "Tracking" or "Shut down" mode. When it enters "Tracking" mode it power up and reset the GSM/GPS module before it enables power to the GPS part of the modem. The reason powering up the GPS early in the initialization process is that it can take some time before obtaining a GPS satellite fix. Next the GPRS connection is established with the server and if anything goes wrong in the process it restarts the GSM/GPS modem and retries. When the connection is established it sends a message to the UTM with information about the ID and the DroneID device software version. After this the device begins transmitting updates containing position, heigt, battery voltage and RSSI at a fixed time interval. If there is no satellite fix, it transmits an uodate only containing the ID and battery voltage. The DroneID device will stop or shut down when the mode is changed.

4.4.3 Communication protocol

The DroneID device communicates with the UTM via GPRS using the UDP protcol. In this work a basic ASCII protocol based on the standard NMEA 0183 protocol was used. The reasoning behind this was that software libraries for NMEA 0183 are readily available and thus the development time was decreased significantly.

The next version of the DroneID device and UTM service should implement a binary protocol including a proper Cyclic Redundancy Check (CRC) of the transmitted data and support for end to end encryption.

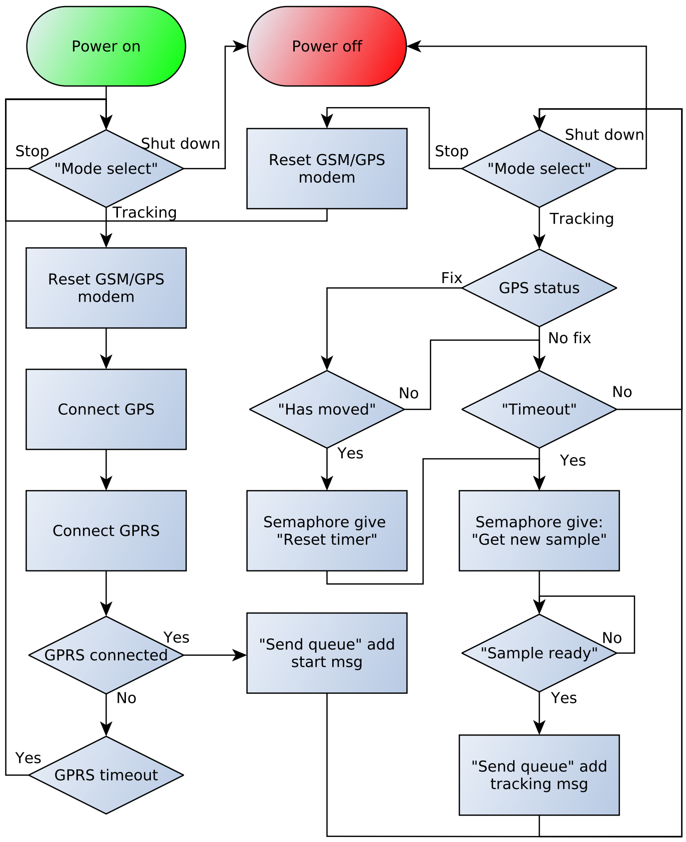


Figure 14: *Flowchart showing an overview of the main steps of the main task.*

4.5 Discussion

In this section the DroneID v1 is documented with a focus on choices made, the reasoning behind and the experiences obtained during performed tests and experiments.

The system design requirements defined in section 3.3.1 have been met to the extent possible and relevant for a first prototype. End to end encryption has not yet been implemented though.

The system design goals defined in section 3.3.2 have been achieved in the contect of a first prototype with the following comments: The bill of materials for a single DroneID v1 device is roughly 700 DKK. This reflect single component prices, PCB production and no expense for the assembly. A significant part of the expences is related to the GPRS modem. An assessment of the cost of producing a large number of a product matured version has not been made, but this solution will probably not be ideal for use on all private drones though.

The DroneID device design requirements defined in section 3.6.1 have been met to the extent possible and relevant for a fist prototype. The total weight of 27.4 g is slightly above the stated 25 g, but reducing the weight of the next version is easily achieved. The DroneID v1 is not weather sealed, but this is also achievable for the next version.

The DroneID design goals defined in section 3.6.2 have been achieved in the contect of a first prototype with the following comments:: Design guidelines for reducing EMI have been followed but subsequent testing of the EMI levels have not been performed. As discussed in section 5 the DroneID device needs to protrude less from the aircraft fuselage and have a more aerodynamic shape when installed on a fixed wing aircraft. As described in section 5.4 the usability still needs some improvements. A keep it simple approach is vital to the usability, and for the DroneID v2 a "one LED one button" solution should be tested. The external GPS antenna should be evaluated carefully. The antenna performs very well in terms of reception, but if possible it would be much better with a built-in chip antenna in terms of usability, SWaP, weather proofing etc.

The overall conclusion concerning the DroneID v1 is that while there is ample room for improvements and product maturing concerning electronics and usability etc. it did perform satisfactorily in the field experiment.

5 Field experiment

This section describes the field experiment conducted during November and December 2015.

In the field experiment a group of 10 professional drone operators/pilots (pilots) were issued each an external DroneID device. During a 30 day period the drone operators then carried out their usual drone operations with the DroneID device installed and thereby actively transmitting information about the drone flight to an experimental UTM service. The purpose of the field experiment was to gain experience in different areas such as the pilot user experience interacting with the DroneID, how the pilot experienced the concept of being tracked by the DroneID device, possibilities of analysing the logged data, the DroneID device hardware and software etc.

To obtain reference information the drone pilots updated a web based log with detailed information about each flight conducted with the DroneID device installed. This information was used to help analyse the logged data and for troubleshooting when errors occured. During the experiment the drone pilots also had full access to updated information about their own tracked flights. They were able to review their flight graphically which proved to be valuable in some cases where the drone tracking revealed unexpected flight patterns. In all cases the drone pilot was able to review the flight track and explain the cause.

During the experiment the UTM service relayed information about each received DroneID device update to a server run by the company DroneSoft. This gave an opportunity to evaluate the DroneSoft database infrastructure and accompanying apps for drone pilots and for authorities. DroneSoft is described in section 6.2.1.

The field experiment was used as showcase for the workshops held for relevant governmental authorities and agencies. The workshops are described in section 6.

5.1 Drone pilots

The drone pilots participating in the experiment were found among members of the UAS Denmark network after announcement on mailing lists, social medias and at national drone forum meetings. The 10 DroneID devices were distributed to 9 external pilots, 1 was used by SDU during the experiment. The external pilots came from 4 private companies, 1 municipality, 3 from the Danish Emergency Management Agency (DEMA) and one university. Table 2 lists the participants and the drones used in the experiment.

Name	Organization	Drone	Type
Thy Lækageservice	Private company	Mikrokopter	Multirotor
Viacopter	Private company	AutoQuad	Multirotors
Playground	Private company	DJI Inspire 1	Quadrotor
Spektrofly	Private company	sensefly eBee	Fixed wing
Odense Kommune	Municipality	DJI drones	Quadrotors
DEMA Tinglev	Governmental agency	DJI Phantom	Quadrotor
DEMA Næstved	Governmental agency	senseFly eBee	Fixed wing
DEMA Næstved	Governmental agency	DJI Phantom	Quadrotor
Aarhus University	University	senseFly eBee	Fixed wing
SDU	University	EduQuad	Multirotor

Table 2: List of participants in the 30 day field experiment.

5.2 Installation guidelines

The pilots were invited to a half-day workshop at the launch of the 30 day project period. At the workshop the project was presented and instructions were given on the following topics: How to install the DroneID device; how to use the external DroneID device; how to access own data at the experiment website; how to update a log book at the experiment website manually with detailed reference data about conducted flights. The company DroneSoft (section 6.2.1) gave instructions on how to use the DroneSoft pilot App for reporting. Figure 15 shows pictures from the workshop.

(a)

(b)

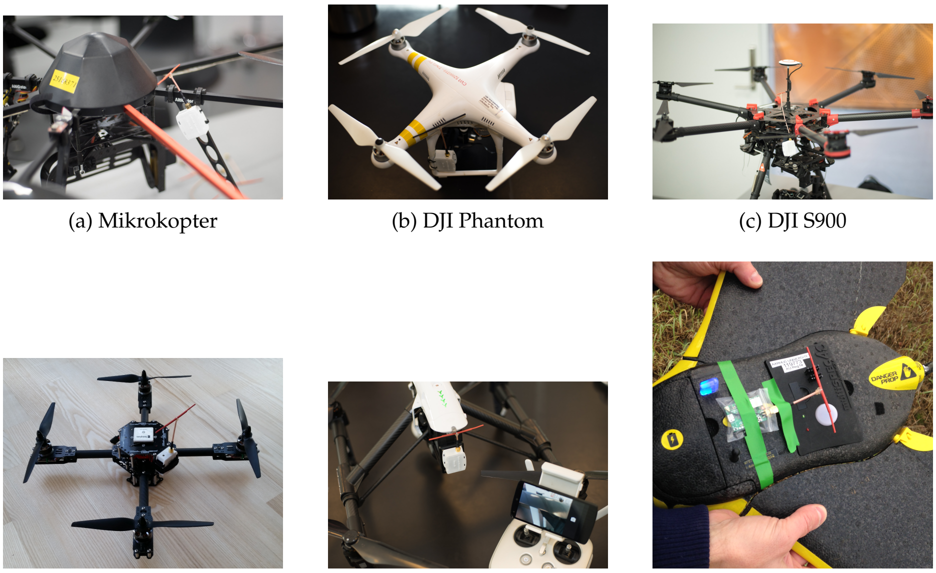
Figure 15: *Drone pilots at the half-day workshop held at the DTCA office. They are installing DroneID devices on the drones used in the experiment.*

The pilots also received a written operator guide for reference during the experiment which contained information about all the above topics. The operator guide is available at the project repository (in Danish). During the experiment the pilots received updated information via email and were encouraged to contact SDU if support was needed. The list below contains the instructions on how to install the DroneID device:

- Installation on the side or beneath the drone body to ensure that the drone GNSS antenna is not obstructed.

- Installation far away from other antennas with the DroneID logo (and hence GSM antenna) facing away from the drone body.
- The external GNSS antenna must have a clear view of the sky without obstructing the drone GNSS antenna or touching propellers.
- The external GPS antenna and cable should not be directly parallel to or near other antennas.
- Mount using electrical tape, velcro, cable binders using the cabinet flanges etc.

Figure 16 shows examples on the DroneID device installations.



(a) Mikrokopter (b) DJI Phantom (c) DJI S900

(d) EduQuad (e) DJI Inspire 1 (f) senseFly eBee

Figure 16: *Examples of DroneID device installations on the drones used in the experiment.*

5.3 Results

Cold, windy and rainy weather conditions during November and December gave less test flights than expected. During the 30 days 19 operator flight days were recorded, each with typically 2-4 takeoffs. Only few flights were conducted in urban environments.

The recorded data provided clear information about the flights and in the cases of a problem or error occured this was reflected well in the data.

For most of the flight days a log entry was added to the web based log providing reference information about the flights.

All external DroneID devices did perform well during the experiment. No sigificant hardware problems occured.

Analysing the data received from the DroneID devices and comparing with the log entries yielded detailed information about the drone flights. The most important issues recorded during the flights were:

- 1 instance of drone entering safe-mode. This happened at SDU and was likely due to placement of GPS antenna with respect to drone RX antenna. It has not been possible to reproduce the error on subsequent flights.
- 2 instances of entire flight days not recorded due to poor GSM coverage and/or software problems.
- Few instances of tracking lost due to low battery on the DroneID device. This problem was identified as a use pattern of keeping the DroneID device active while on the ground.
- User interface was too complicated and buttons were too difficult to reach. The pilot already has many things on his mind while planning and performing flights. The pilot forgets to turn off after use (in a few instances causing recordings of the pilot driving home).
- The GPS antenna solution is less expedient during installation but it worked well with regards to the ability to obtain a GPS fix.
- The current DroneID device housing is too big for the senseFly eBee drone. It works well for multirotors, but when mounted outside the aircraft fuselage on a small fixed wing it needs to protrude less from the aircraft fuselage and have a more aerodynamic shape.

5.4 Discussion

Although a higher number of test flights would have been advantageous, the test flights performed did provide valuable knowledge concerning the pilot interaction with the DroneID and also helped testing the DroneID device hardware and software. Also the ability to demonstrate the experimental UTM service and DroneID devices to relevant stakeholders at the workshops described in section 6 gave valuable feedback.

Flights not recorded due to poor GPRS coverage is an inherent problem in using GSM technology. The DroneID device only supports GPRS, support for the newer GSM based data technologies listed in section 3.4.2 may reduce the problem, but no single GSM network provides 100% coverage of Denmark.

The identified problem of a pilot experiencing a low battery level due to a use pattern of keeping the DroneID device active while on the ground is partly caused by the current DroneID hardware which has hard to reach buttons and LED's that are difficult to observerve, partly because the pilot has many items on the checklists and does not focus on the DroneID, and partly because the current software is not optimized for power saving operation. This is discussed in more detail in section 4.3.4.

All in all the experiment went very well. To the extent tested in this limited experiment the UTM service and DroneID device solution seems feasible. The errors and deficiencies discovered so during the experiment can expectedly be fixed in new versions of the UTM service and DroneID device.

6 Workshops

During the field experiment described in section 5 two workshops for public authorities and agencies were held. This section describes the workshops with a focus on the achieved results.

The two workshops were held respectively halfway through and towards the end of the field experiment. Participants were stakeholders from the Danish National Police, Danish Emergency Management Agency (DEMA), Danish Defence, Naviair (ANSP), UAS Denmark and DTCA (CAA).

The agenda for the first workshop was a presentation of the project and tentative results, and presentations by the industrial partners described in section 6.2. This was followed by a live demonstration at a nearby drone airfield focusing on the DroneID hardware and user interface through web and apps. The weather conditions on the day of the workshop presented high winds and gusts well beyond 15 m/s, so only limited flying with one quadrotor drone was possible. Thoughout the workshop the participants gave feedback to the project and industrial partners.

The agenda for the second workshop was similar to the first, however most content was updated based on the learning points from the first workshop, subsequent updates and improvements, and updated results from the field experiment. The demonstration was held at the national drone test under normal weather conditions. 3 multirotors and 1 fixed wing drone were used during the live demontration.

6.1 Feedback

Following the demonstration at the second workshop was a session on feedback and suggestions for a future DroneID system by the authorities and agencies. This session was supplemented by a request for written statements from the authorities after the workshop, to which the National Police, DEMA and Naviair responded. Section 6.1.1, 6.1.2, 6.1.3 and 6.1.4 contain the main feedback notes.

6.1.1 National police

- An increasing number of inquiries from citizens concerning drones flying near private property, gardens, beaches etc. is expected to take up significant resources as drones become more common.
- Observe and identify unauthorized drones near an ongoing police action.
- The solution should be accessible from operational centers without requiring infrastructure or officers near the drone.
- The solution should be usable by officers on foot and thus not not require fixed installations in police vehicles, on buildings etc.

6.1.2 Naviair

- Observe and identify drones inside and near areas controlled by the ANSP (control & information zones around airports, military, dangerous, restricted and prohibited areas).

- Ability to contact the drone pilot during flight.
- Possible use of geofencing for restricting the drone ability to enter the controlled areas.

6.1.3 Danish Emergency Management Agency

- Seamless live monitoring of emergency management drones as well as unauthorized drones near an ongoing incident.
- Live and historical documentation of area coverage during searches.
- Support a division of an operation into sectors when performing large scale searches such as sea accidents.

6.1.4 General comments

- On-site monitoring of a drone beacon signal combined with a relay of updates to UTM through the pilot's smartphone raises concerns regarding reliability.
- The possibility to use the Danish safety network SINE[30] rather than GSM was discussed.
- Possibly synergy by combining DroneID tracking information with ADS-B data such as presented at flightradar24.com[31]
- Possible synergy by issuing similar ID's to soaring planes, para gliders, hang gliders etc.

6.2 Industrial collaboration

The industrial companies associated with the DroneID project were chosen based on their ability to contribute to the the project aim of building new knowledge and experience in monitoring drones. They each presented results of their current efforts in developing new products and services focusing on UTM. Their individual contributions are described in section 6.2.1, 6.2.2 and 6.2.3. Company product sheets and presentations are available at the project repository.

6.2.1 DroneSoft

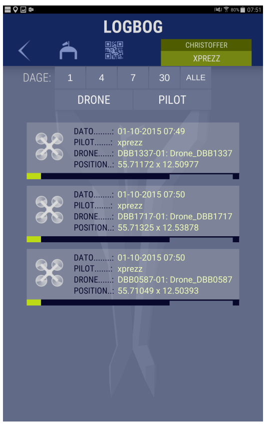
Dronesoft ApS[32] is a software company developing a DroneSoft platform providing integration of drones and drone devices into enterprise applications and systems. The version of DroneSoft presented at the workshops facilitates some UTM functionality targeted towards drone operators and pilots and the authorities. A drone

[30] http://www.sikkerhedsnet.dk/en/
[31] http://www.flightradar24.com/55.5,10.48/7
[32] http://www.dronesoft.com

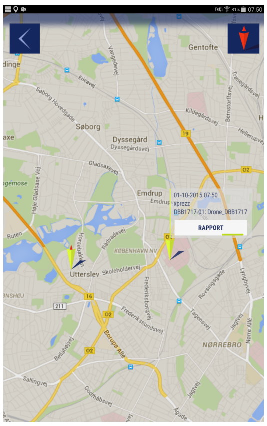
operator interface provides registration of operators, pilots and drones, submission of flight plans, log book etc. An interface for relevant authorities provides live and historical access to identification and monitoring of drone flights. The DroneSoft platform is based on a SiteCoreTM and SQL enterprise backend architecture. The user interface is provided via iOS/Android apps and a website, screenshot examples from the apps are shown in figure 17. The DroneSoft platform supports integration of multiple sources of drone and drone device data such as the DroneID device.

(a) Flight log entry

(b) Flight log entry



(c) Log view



(d) Map view

Figure 17: Screenshot examples from the DroneSoft Apps.

The DroneSoft platform was used in the field experiment described in section 5 for the purpose of demonstration and to provide feedback to the developers. The participating operators and pilots were each issued a DroneSoft account and thus had the opportunity to use DroneSoft during the experiment. In addition all DroneID device updates were relayed from the DroneID server to the DroneSoft platform.

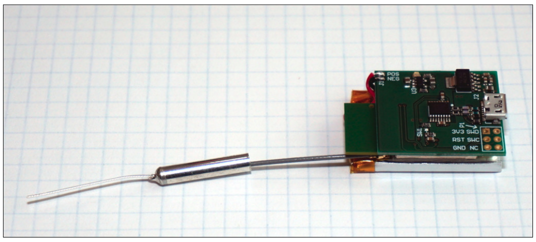


Figure 18: *DroneID beacon*

6.2.2 RESEIWE

RESIEWE A/S[33] develops Resilient Wireless Links (ReWiLink) for mission critical applications based on existing equipment and standards.

At the workshops RESIEWE showcased an external device transmitting a local beacon signal (see section 3.4) using 2.4 GHz Wifi. ReWiLink is used for range extension while maintaining compatibility with standard Wifi, and the signal is thus readable using a standard smartphone. The use of ReWiLink does not invalidate the certification of the Wifi module. Tests using a Samsung S4 smartphone with a RESIEWE app installed has demonstrated successful line-of-sight communication at a range of 1.2 km. Using a hand held reader developed by RESIEWE a range of 2.2 km has been demonstrated. For more information please see the project repository.

The device has a weight of less than 10 gram which is about half the weight DroneID device without casing. Figure 18 shows an early prototype of the device without GPS. The power consumption is significantly lower than the DroneID device and the hardware cost is expectedly lower as well due to the use of Wifi technology vs. GSM based technology.

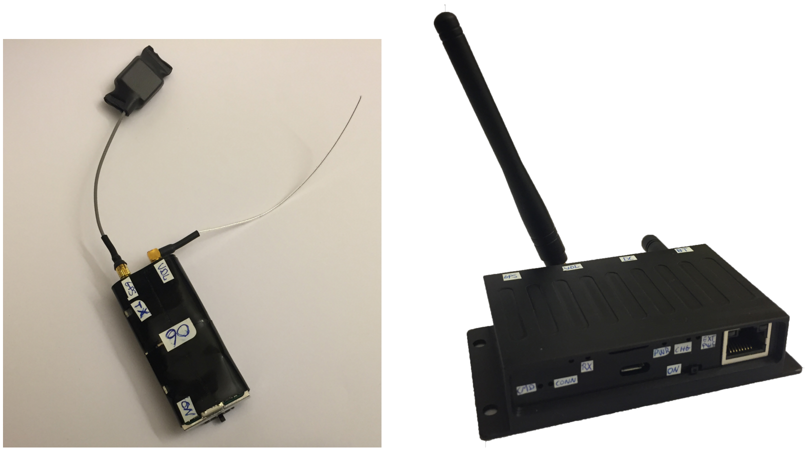
6.2.3 SCANDINAVIAN AVIONICS

SCANDINAVIAN AVIONICS A/S[34] supplies turn-key avionics solutions including certification, design, installation, maintenance, product development and training for civil and military aviation.

At the workshops SCANDINAVIAN AVIONICS showcased a transponder device using a local beacon signal (see section 3.4) based on the ICAO standard for VHF Data Link (VDL) mode 4 technology. The device supports air to air, air to ground and ground to air communication, where ground communication is handled by a dedicated ground unit. The system supports handling of up to 75 transponders within line of sight at an update rate of 1 second. The device has a weight of less than 30 gram and is sized 20x50 mm.

Figure 19 shows the transponder and ground unit. Figure 20 shows the transponder tentatively mounted on a drone and the resulting map output from two simultaneous drone flights.

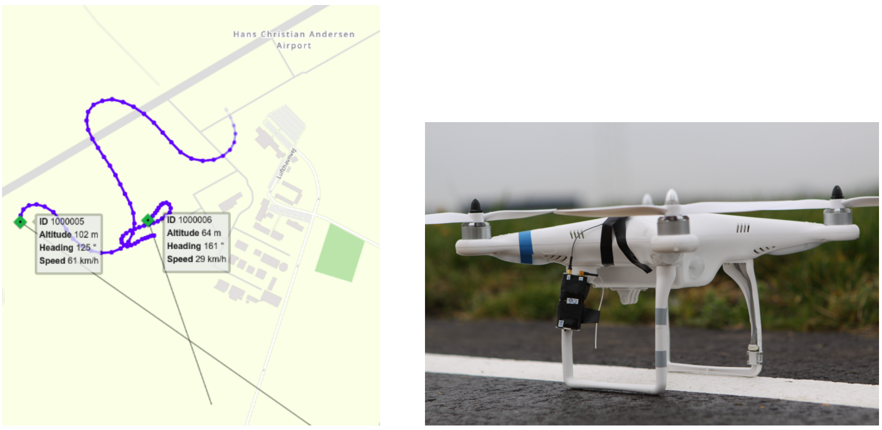
[33] http://reseiwe.com
[34] http://www.scanav.com



(a) Transponder with connected GPS device.

(b) Ground unit

Figure 19: SCANDINAVIAN AVIONICS transponder and ground unit.



(a) Map example showing two simultaneous drone flights at the second workshop.

(b) Tentative installation during the second workshop

Figure 20: SCANDINAVIAN AVIONICS example map and drone installation.

6.3 Discussion

Two workshops were held for public authorities and agencies. At both workshops the progress of the DroneID project was presented and demonstrated.

The industrial companies associated with the DroneID project each demonstrated their product prototypes within UTM software and drone beacon systems. The demonstrations and associated presentations were a valuable addition to the results of the DroneID projects presented by SDU at the workshops.

During both workshops feedback was received through informal discussions. The second workshop also included a formal session on feedback from the participants, and some agencies provided written feedback as well. The feedback has been processed and the result is implemented in the system design described in section 3 as design requirements or design goals.

7 Discussion

Each main section in this report is concluded by a discussion of the results and findings. This section discusses the overall project results and the relation to the future work.

The related work presented in section 1 clearly state the need for an implementation of UTM in the near future to enable safe, efficient low-altitude operations of small drones. The identification and tracking of small drones is an integral part hereof, and the aim of this project is to build knowledge and experience within this area.

The system design presented in section 3 is based on a review of related work, input from a number of stakeholders, and the experience obtained through the development activities and experiments conducted in this work. The stakeholders include drone pilots, technical and non-technical domain experts, decision makers, authorities, governmental agencies, the industry and politicians. This heterogeneous group also represent the target audience for the reporting of this work, therefore a technical report was chosen rather than a scientific paper. Focus has been on conveying results and findings at a generic level while at the same time providing the details necessary for experts to build upon this work.

Section 4 describes a first prototype of an external DroneID device for transmitting updates from a drone to the UTM. The focus has been on establishing a proof of concept in a short period of time rather than seeking optimal solutions to all technical parts of the project. The DroneID device transmits the drone identification, position and height, battery level etc. each second to the UTM via GPRS. The built-in battery last for about 2 hours of operation. The unit is fully self-contained and weighs 27 g. There is ample room for improvements on both the battery lifetime and device weight. It is estimated that an implementation of a similar functionality by a manufacturer will weigh 3-5 g.

In the field experiment presented in section 5 The DroneID device and a prototype of a UTM service supporting identification and tracking were tested. A group of 10 professional drone pilots were issued each an external DroneID device. During a 30 day period they then carried out their usual drone operations with the DroneID device installed and thereby actively transmitting information about the drone flight to an experimental UTM server. Weather conditions prevented drone flights on many days during the experiment. 19 pilot flight days were recorded, each with 2-4 take-offs. The recorded flights did provide valuable knowledge concerning the pilot interaction with the DroneID device and helped testing the hardware and software. Data received by the UTM has been analysed and compared with detailed logs provided by the pilots. Some issues concerning technical design and usability were discovered, and the proposed system design has been updated accordingly.

Two workshops described in section 6 were held for public authorities and agencies respectively halfway through and towards the end of the experiment. At the workshops the current progress of the project was presented and discussed. The industrial partners associated with the project presented their respective prototypes of components for UTM and added hereby great value to the workshops. The prototypes were also demonstrated during drone flights. Feedback received during and after the workshops has been implemented in the system design.

Based on the results obtained in this work it seems feasible to to efficiently identify and track drones fitted with the external DroneID device by a UTM service. The project has contributed with relevant knowledge and experience, but further research and development is needed before a full deployment will be possible. The DTCA and SDU have therefore agreed to launch a subsequent project. This project will include further development of the DroneID device and the experimental UTM service for identification and tracking. A more extensive experiment will be performed involving more drone pilots over a longer time period. The experiment will focus on the UTM service integration with relevant stakeholders (section 3) including use of the identification and tracking by the authorities and the public, and on technical testing of the updated DroneID device.

Concerning the DroneID v1 device some of the design choices made were found to be less than optimal. Most notably the feasibility of embedding the GNSS antenna within the casing will be explored. The integrated GPRS and GPS module described in section 4.3.2 did not perform satisfactorily and will be replaced by another product. The processor will be upgraded to support onboard signal processing of sensor data as well as encryption. The battery life time issues described in section 4.3.4 should be solved. In addition to the proposed solution of varying the update transmission rate, significant power reduction may be achieved by utilizing low power features of the processor and GPRS and GNSS modules.

The experimental UTM service will be extended to support an entry point for the authorities and the public in order to conduct the new experiment. By communicating from the UTM service to the DroneID it will be possible to signal to the pilot using the LED if the drone for some reason is not allowed by the UTM to take off. Also more extensive logging of sensor data from the DroneID device is expected provide new valuable knowledge. One example is the RSSI of the communication link which will be used in combination with the GNSS positioning to create coverage maps. The maps may document the overall UTM radio coverage but may also be able to assist in identifying specific drones where the DroneID device shows a less than optimal coverage due to eg. improper installation.

At the time of publication of this report a prototype of the DroneID v2 device is being tested by volunteer professional pilots. Only very limited tests have been performed until now, but based on the results so far, the device seems to work as expected. The DroneID v2 device is smaller than the DroneID v1. It weighs about 20 g and is weather sealed to conform with IP53[35] corresponding to a protection against dust and spraying water. The DroneID v2 device therefore comply with the design requirements stated in section 3.6.1. The user interface is currently being simplified significantly to improve the usability.

[35]Ingress Protection, IEC Standard 60529

8 Conclusion

This section contains the report conclusion including the future work and perspectives.

In this work we propose a system design for a drone identification and tracking system in Denmark. The aim is to support the authorities in enforcing drone regulation, and the system is expected to be implemented into a UAS Traffic Management (UTM) service.

The proposed system design supports communication between the drone and the UTM via either a local beacon signal or a radio network infrastructure. Both solutions have advantages and drawbacks, and the choice is influenced by some fundamental questions: Will the use be required everywhere or only within cities? Will it be required by professional pilots only or recreational pilots as well? Will the functionality be implemented by the manufacturer or is installation of an external device required. The optimal solution may be a combination of the two.

To establish a proof of concept, a prototype of an external DroneID device and an experimental version of UTM supporting identification and tracking was developed. The DroneID device transmits the drone identification, position and height etc. each second to the UTM service via GPRS.

An experiment was conducted in the fall 2015. During a 30 day period a group of 10 volunteer professional drone pilots carried out their usual drone operations with a DroneID device installed on their drone. The recorded flights did provide valuable knowledge concerning the pilot interaction with the DroneID device and helped testing the hardware and software. Some issues concerning technical design and usability were discovered, and the proposed system design has been updated accordingly.

Two workshops were held for public authorities and agencies respectively. Current progress of the project was presented and discussed, and industrial partners associated with the project presented their respective prototypes of components for UTM. Feedback from the workshops has been implemented in the proposed system design.

Based on the results obtained in this work we conclude that it is feasible to deploy a drone identification and tracking system in Denmark. The project partners have agreed to continue the project. A new version of the external DroneID device is currently being developed and a larger scale integration experiment will be conducted in 2017.

Software and hardware developed within this work has been released as permissive free open source for others to build upon.

9 Acknowledgements

The authors would like to thank UAS Denmark for the work that this report builds upon, drone operators and pilots participating in the field experiment, governmental authorities and agencies for participating in the workshops and contributing with valuable feedback, Dronesoft ApS for their contributions to the project concerning an UTM database and tablet showcase, Resiewe A/S for contributing to the project by showcasing their algorithm for a reliable wireless data link, Scandinavian Avionics A/S for contributing to the project by showcasing their transponder prototype, More Electronics for providing samples and support concerning ublox GPS and GRPS modules, Viacopter for providing the GPS antenna design, UAS Test Center Denmark and the model airfield association of Copenhagen for providing airfields for workshop demonstrations, Jussi Hermansen, Viacopter and Kim Kristensen, Odense Municipality for piloting drones at the workshop demonstrations, Carsten Albertsen, SDU for the DroneID device hardware design, Jørgen M. Pedersen, SDU for the DroneID cabinet design. Christian Struwe, DJI for valuable information about related work.

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